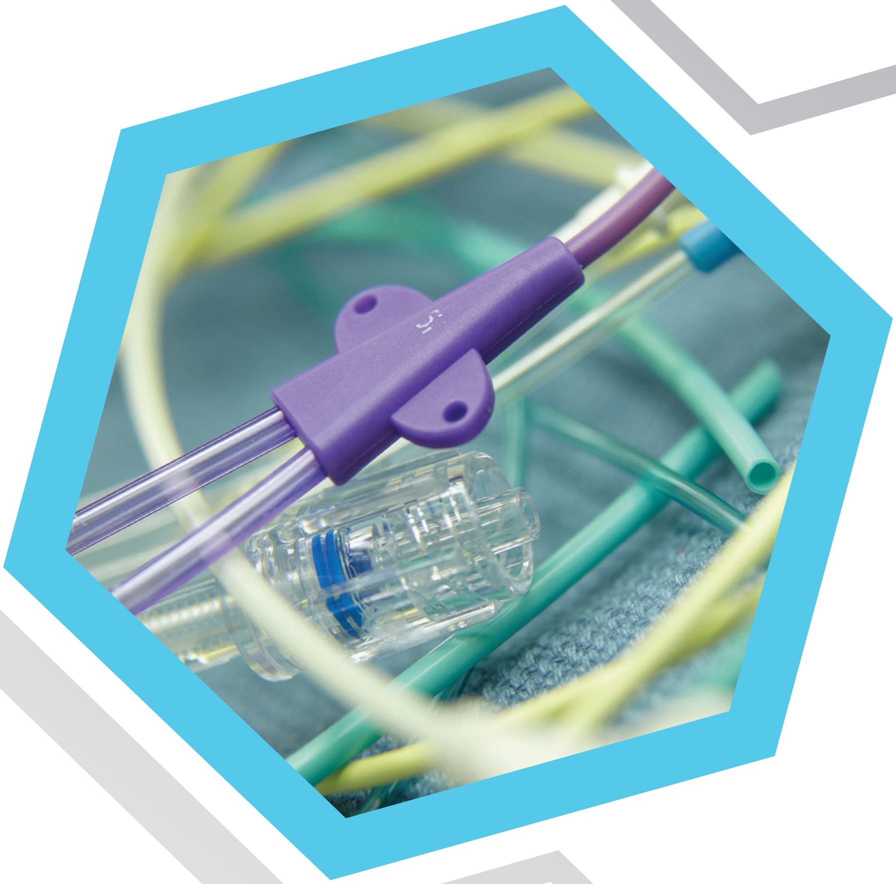
Lubrizol LifeSciences

POLYMER SOLUTIONS

Extrusion Guide



Lubrizol

Lubrizol LifeSciences

Extrusion Guide

Contents:

Introduction

Lubrizol LifeSciences (LLS) is a business within The Lubrizol Corporation that provides innovative polymer solutions for healthcare products. Among the chemical technologies employed by LLS are thermoplastic polyurethane elastomers (TPUs). The LLS TPUs are grouped into several families of products with varying chemical and physical characteristics. They can be readily converted to flexible, elastic forms such as tubing and film on conventional thermoplastic extrusion equipment.

This brochure is intended to provide general guidelines for equipment, procedures and extrusion conditions that will help the customer obtain the best possible performance from the LLS line of TPU extrusion grades. Additional information can be obtained by consulting individual product Technical Data Sheets or by contacting your Lubrizol LLS technical service or sales representative.

Materials

The LLS TPUs are available in both aromatic and aliphatic types. The choice of polyol raw material during manufacture leads to the families of polyester, polyether and polycarbonate grades. Separate LLS literature is available describing detailed properties of the various classes and grades. All of these TPU types have common characteristics as far as extrusion processing behavior and practices. This guide covers those general characteristics.

TPU Crystallinity

TPUs are generally not considered to be crystalline polymers that would be represented by a product like low-density polyethylene (PE). Some of the harder TPU grades (~> 90 Shore A) could be considered semicrystalline. Softer grades (~62A–85A) can be nearly amorphous — they have no definite melting point but soften gradually on heating. Upon heating and shear mixing within an extruder, they achieve a viscous fluid state characteristic of a polymer much like low-density polyethylene. Melt viscosities suitable for extrusion will be achieved at temperatures well below the point of degradation. Initial softening points range from 250°F–340°F (121°C–171°C) while melt temperatures suitable for processing will be generally about 20°C higher.

Harder grades will require higher temperatures to achieve a homogenous melt. They will also have a narrower processing temperature range in which the melt viscosity is suitable for forming extrudate profiles. This behavior is a consequence of the degree of crystallinity of the TPU; in general, harder TPUs have higher crystallinity and require more heat/shear to melt.

Grades identified as injection molding grades generally are harder (~> 50D) and have this narrow processing range. Molding grades are usually not suitable for extrusion.

There are some hard (~> 50D) TPU extrusion grades. Greater diligence in the processing operation is required. For example, slow-moving materials can solidify within the extruder by an annealing process. Cloudy particles in the extrudate can indicate sloughing of annealed TPU.

Extrusion conditions specific to individual grades can be found in the product Technical Data Sheets.

Maximum Processing Temperature

Temperatures in excess of 450°F (232°C) may result in polymer degradation as evidenced by bubble formation within the TPU melt. If this occurs, a reduction in zone temperatures will restore bubble-free extrudate and stabilize extrusion conditions. Generally, temperatures near this maximum result in melt viscosities that are too fluid to maintain a viable form (tube, film, etc.) when exiting the die.

Melt Viscosity

A key TPU variable critical to extrusion processing is the molecular weight. This is directly related to the length of the polymer chain. This variable governs the melt viscosity achieved by the material in an extrusion process; higher molecular weights create higher melt viscosities, which in turn have higher melt strengths when measured at the same temperature. Of course, melt strength determines how easily a melt can be handled to form a rod, a tube, a film, etc.

Lubrizol TPU business has determined that the TPU molecular weight, melt viscosity, etc., can be correlated to the melt index (MI) of the material. The relationship of melt viscosity to melt index is inverse: higher molecular weight, higher viscosity TPUs have lower MIs. Conversely, lower molecular weight, lower melt viscosity TPUs have higher MIs. With years of experience and hundreds of customer experiences, Lubrizol has determined the optimal melt index range that is suitable for each product and the extrusion process that would be used. For example, TPUs designed for fabric coating generally require lower melt viscosity (higher MI); the lower viscosity provides a fluid melt to level out. The fabric provides support for the lower viscosity. Conversely, TPUs intended for tubing may have higher melt viscosities (lower MI) to better maintain the unsupported shape.

Melt index is routinely determined for nearly all LLS TPU grades. In comparing the MI of one TPU grade to another, it is critical that the MIs of both materials be carried out under the same conditions of temperature and load. Although 190°C/8700 grams is a common TPU MI condition, there are many other combinations of temperature/load.

The individual MI value on a single box, bag or lot of TPU is generally of importance as it relates to prior experience with the product. Small changes to the extrusion process may be required if the MI is different. Customers extruding large quantities of TPU continuously may stage their pallets of material by MI. Generally, it is better to run high MIs (lower viscosity) followed by low MIs (higher viscosity).

Blending of TPU pellets to achieve a different set of properties is generally not recommended. Mixing an 80A TPU with an 85A TPU will achieve an intermediate hardness TPU extrudate, provided that the materials successfully melt blend in the extruder. Achieving a uniform melt in a single-screw extruder can be difficult with a mixture of soft and hard TPU pellets. In addition to the difference in hardness, the TPUs may also vary in melt viscosity (MI), as well.

A similar melt uniformity concern occurs when regrind is used. Depending on the extrusion conditions at the time the “regrind product” was created, the MI may be very different than virgin resin. The shearing process can break polymer chains, resulting in a lower-viscosity (higher-MI) material. When this is mixed with lower-MI virgin resin, achieving a uniform melt may require significant adjustments to the process. The worst combinations to process are low percentages of low MI mixed with high percentages of high MI. Knowing the MI of regrind may be important.

Basic Guidelines

LLS TPUs must be properly dried before processing. There are no grades which can be reliably extruded without drying. Although LLS TPUs have low moisture content when manufactured, TPUs are hygroscopic (absorb and retain water from the air). Subsequent handling, transportation and storage conditions can increase the moisture content. Inadequate drying can result in a loss of properties of the extruded product and may give a poor appearance. Extruder barrel and die temperatures must be set properly for each product. Deviation from the 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 LLS TPU compounds 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 is added to virgin TPU, then these materials must also be properly dried and may have a significant impact on the quality of the product. 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 TPUs. Even during short breaks, material should be kept moving at slow rates through the system. This is particularly critical for the hard grades, which may undergo an annealing process within the extruder and become more crystalline, and in excessively long stagnant downtimes, can solidify.

Equipment

Dehumidifying Hopper Dryer

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

Because of the relatively high consumption rate of an extruder, a good desiccant hopper drier is a preferred method for delivering consistently predried and preheated 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 aromatic LLS 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). A dewpoint of -40°C should be targeted. Review the product's Technical Data Sheet for specific drying instructions.

A device to measure actual moisture content of the resin may also be used, since dryer malfunctions can occur. Instruments that measure weight loss are suitable, as water is the only significant substance that contributes to weight loss. Refer to individual Technical Data Sheets for drying recommendations that may be specific to a grade.

Extruder

Most extruders are electrically heated with either band-lye 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.

The optimal extruder barrel length for LLS TPUs is 30–32 times its internal diameter (30:1 L/D, 32:1 L/D). Although shorter barrels such as 24:1 can be used, mixing efficiency and melt uniformity may be less than optimal. Cooling 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

A properly designed screw should melt the pellets and subsequently homogenize the TPU melt 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 suggested at the end of the screw, particularly if color concentrates are added. The best performance has been with the Saxton and pineapple-type mixers.

The design recommendations for a series of 30:1 and 24:1 screws are listed in **Table 1**. Proper maintenance of the screw will pay off in higher-quality output, quicker startups, better output rates and more reliable run-to-run performance consistency.

Figure 1 Extruder

A - Drive
B - Feed
C - Screw
D - Barrel (heater bands)
E - Barrel Liner
F - Screen Pack
G - Breaker Plate
H - Die Body
I - Die Head

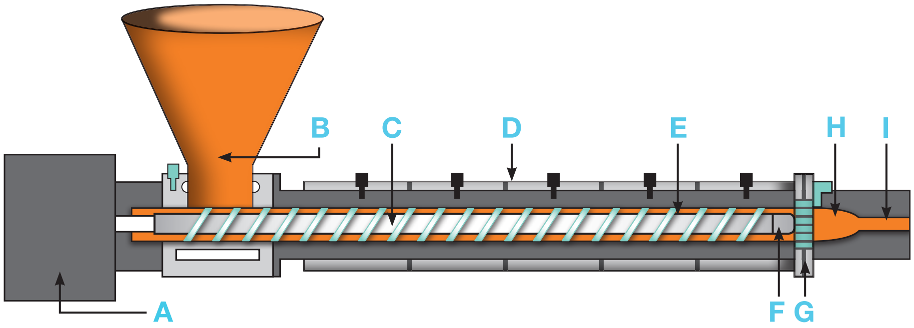


Table 1

Suggested Screw Design for Extrusion of Lubrizol LifeSciences Thermoplastic Polyurethanes				
Extruder Size	**1½"**	**1½"**	**3½"**	**4½"**
Recommended Horsepower	25	25	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"	0.270"	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"	0.090"	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
L/D ratio	24/1	24/1	24/1	24/1
Feed Section – number of flights	6	6	6	6
Feed Section – flight depth	0.285"	0.285"	0.45"	0.525"
Transition Section – number of flights	9	9	9	9
Metering Section – number of flights	9	9	9	9
Metering Section – flight depth	0.095"	0.095"	0.150"	0.175"

Feed Throat

Feed throat cooling with water is frequently recommended to provide protection for the drive bearings and to prevent bridging and agglomeration of the pellets entering the screw. Ambient tap water is adequate; the flow rate should be slight to moderate.

Pressure Gauges

Changes in melt viscosity and output should be monitored by a melt pressure gauge. Monitoring melt pressure provides an indication of extrudate quality and/or uniformity. It is also helpful at startup to determine whether there is proper flow, if the material is bridging in the feed throat or freezing off in the die. If it is freezing off in the die, head pressure beyond the extruder's operating limits may occur. Diaphragm-type transducers are preferred because they are responsive and very accurate. Bourdon gauges that use silicone grease to transmit melt pressure are also satisfactory in many instances.

Breaker Plate and 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. Review the specific product's Technical Data Sheet for recommended processing information. 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. Screens and breaker plates increase the back pressure. Provided that this is not excessive, this pressure can facilitate the homogenization of the TPU melt.

Dies and Takeup Equipment

Die and takeup 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

Streaks or Die Lines

These are generally caused by buildup in the die or damage to the die. You will likely need to clean your die. Best results are obtained by shutting down after purging with a non-TPU resin like PE.

Sticking or Blocking

TPUs are generally tacky. Insure that the proper formulation is being fed to the extruder. Check the coating on your rollers. A nonstick coating is required and can be damaged over time.

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; 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 may be adding (regrind, masterbatch, etc.). If possible, try a different lot of resin; if the problem is solved, contact your Lubrizol representative. Saving a sample of the problem lot and a lot that worked on your process can be helpful in avoiding the problem in the future. What appears to be cloudy contaminants is a separate issue that should be reviewed with a Lubrizol representative.

Nonuniform 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.

Nonuniform Thickness in the Transverse Direction

This is seldom a resin issue. Insure that the adjusting bolts are properly set. Check your system for buildup. Check for nonuniformity in cooling. There is a detailed Troubleshooting Guide at the end of this Processing Guide.

Polyurethane Films

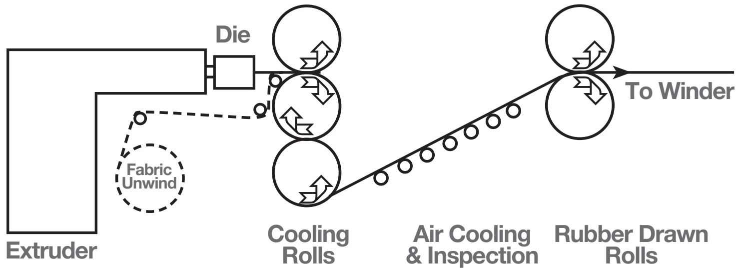
As a film, TPU is soft but very tough. It can be made by film-blowing, extrusion-casting, solution-casting or by calendering. TPU film has a very high tear strength and high abrasion resistance, and is extremely resistant to oils and greases. This combination of properties has led to its use for specialized packaging, sheaths for films for wound care, medical instruments, garments, bags and other medical supplies.

Cast Film and Sheet Extrusion

Procedure

The process for extruding film and sheeting is illustrated in **Figure 2.** 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.



The dotted line indicates a fabric lamination possibility.

By convention, gauges of thermoplastic webs under 0.010” are called “film,” whereas gauges in excess of this thickness are usually called “sheet.” Some soft grades of LLS TPU will require the use of a release liner or the addition of lubricants to the formulation to insure blocking does not occur. Most extrusion grades of TPU can be converted into cast film or sheet. Rarely are TPUs extruded into sheet > about 0.250” thick. Refer to the Technical Data Sheet for information on specific materials.

Equipment

Dies

Generally, successful extrusion of film of polyurethane is accomplished with a flexible lip film die as in **Figure 3,** whereas heavier gauges up to 0.25" 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 Sheet Die.

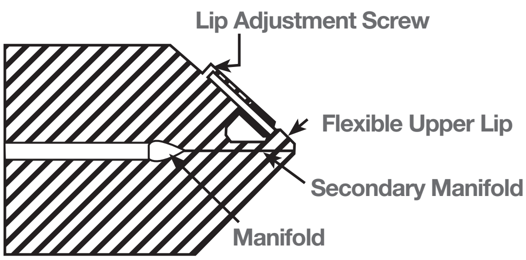
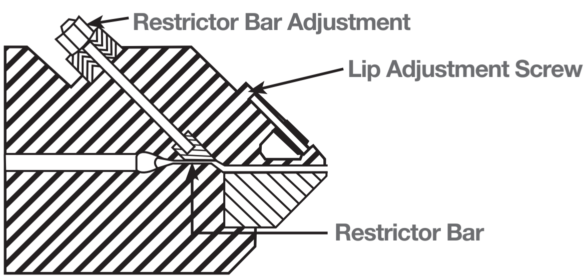


Figure 4 Flexible Lip Flat Sheet Die with Adjustable Restrictor Bar.



Flat sheet dies are heated with electrical resistance cartridge heaters placed in holes drilled in areas carefully selected to avoid localized hot spots that would affect melt flow uniformity. It is important to keep the drawdown to a minimum. This should be 20:1 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.** LLS 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 windup equipment.

Dies

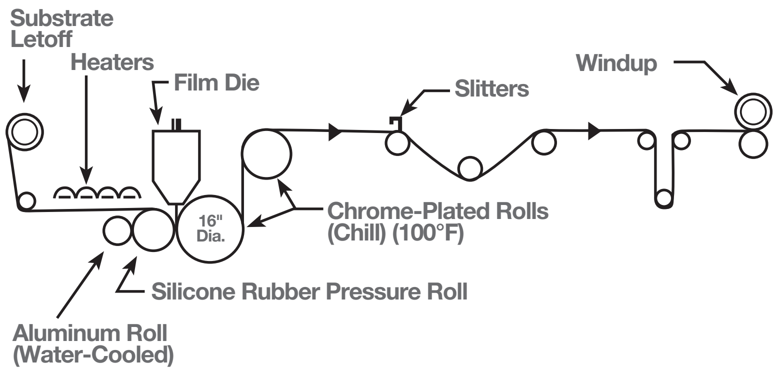
The die design that has been found to be most suitable for the flow characteristics of LLS TPU compounds has a coat hanger flow pattern and teardrop cross-section as illustrated in **Figure 3**. A heated adapter tube carries the TPU melt from the extruded head to the opening in the center-fed die. For best results, the adapter tube and die should be maintained carefully 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**.

Figure 5 Extrusion Coating Line



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 and Rewind

Sophisticated tensioning, positioning and aligning devices are normally installed between the unwind and windup 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.

Preheat

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

Several types of specialty urethane adhesives may be considered for bonding the TPU compounds to various substrates.

Startup 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–200°F for improved bonding.

Blown Film

Procedure

The importance of drying has been covered in the preceding text on drying (see Equipment). 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.

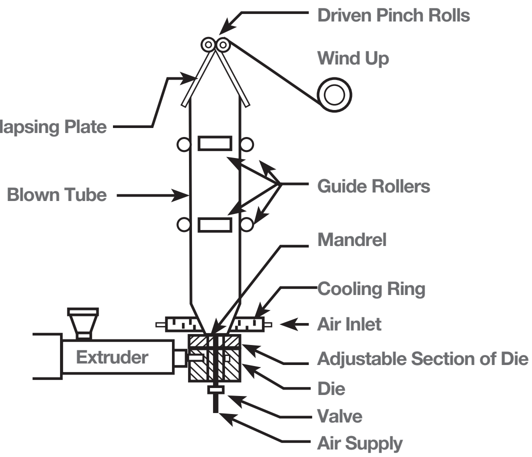
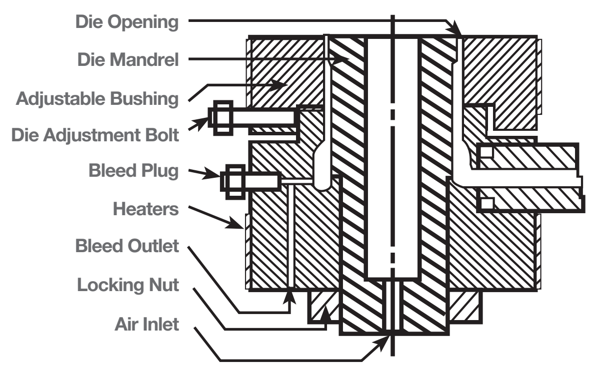


Figure 7 Blown Film Die.



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 compounds 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 (tetrafluoroethylene)-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 grades of TPU 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.

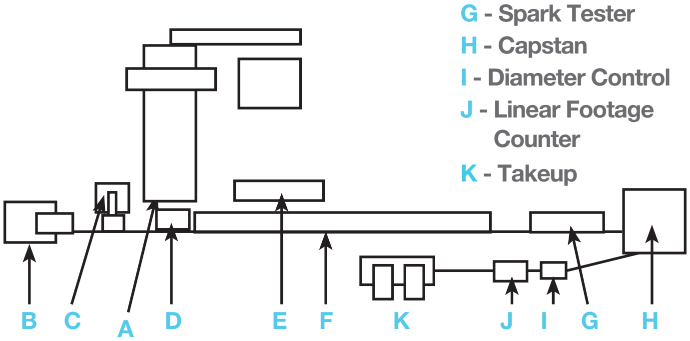
Wire & Cable Coating, Hose Jacketing

Procedure

The process of coating wire & cable by extrusion is diagrammed in **Figure 8.** LLS polyurethane 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˚.

Figure 8 General Wire Coating Setup.

A - Extruder
B - Payoff
C - Preheater
D - Crosshead Die
E - Controls
F - Cooling Trough
G - Spark Tester
H - Capstan
I - Diameter Control
J - Linear Footage Counter
K - Takeup



It is in the crosshead that the wire, coming from the unwind and preheater, 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. The driven capstan pulls the hot-coated wire through the water-cooling trough and the high-voltage spark tester. The choices of die opening, capstan speed and screw RPM are all variables that determine the dimensions of the coated wire.

Equipment

Unwind

Very small single conductors 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 multistrand 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.

Preheater

Preheating 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 preheating can be done with either a gas flame or water-cooled quartz preheater 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 Carboloy.

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.

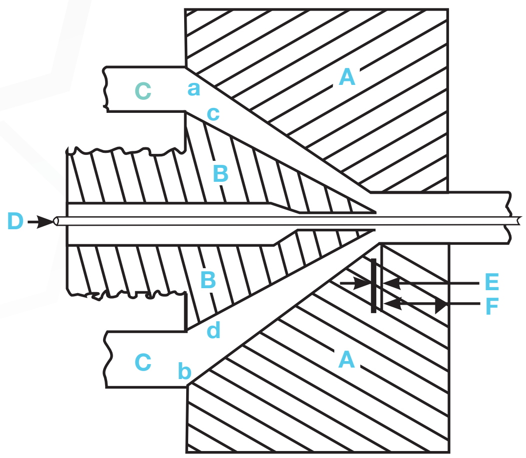
Cooling Trough

All thermoplastic 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.

Takeup

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.

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



A - **Die**

B - **Tip (O.D. inside tip approximately 1 mil over the O.D. conductor. A die O.D. of 5% larger than the O.D. of the insulation should be used as a starting point.)**

C - **Melt Flow**

D - **Conductor**

E - **Land = O.D. of extrusion**

(Land ratio = $\frac{\text{Land Length}}{\text{O.D. of insulation}}$ **)**

A ratio of 1:1 meets most applications; 2:1 for thin walls.

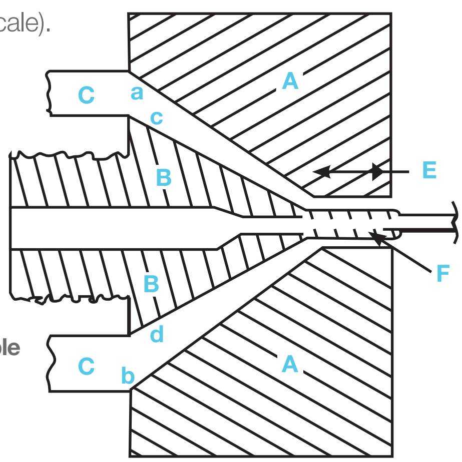
F - **Tip Spacing (Tip spacing must at least equal wall thickness.)**

a - **b** - **Die Angle**

c - **d** - **Tip Angle**

(Tip angle should be slightly less than die angle.)

Figure 10 Tubing Die (Not to Scale).



A - **Die**

B - **Tip**

C - **Melt Flow**

D - **Air (or conductor passageway)**

E - **Die Land = O.D. of finished cable**

F - **Outside Tip Land**

a - **b** - **Die Angle**

c - **d** - **Tip Angle**

Normal drawn-down for wire cable is between 10-15%. This may be aided br the use of a vacuum of at least 20mm of mercury. The clearance between Conductor and the Guider in the land area = 0.005".

A. There are two common ways of calculating drawdown ratio. The 10-15% mentioned above is based on the linear ratio of

$$\frac{D_1 - T_0}{\text{O.D.} - \text{C.}} = \frac{1.10}{1} \text{ to } \frac{1.5}{1}$$

The second one described by the ratio pertains to the cross sectional area of the die gap divided by the cross-sectional area of insulation. The ratio calculated by the method should be 1.50:1 to 1.75:1.

$$\frac{(D_1)^2 - (T_0)^2}{(\text{O.D.})^2 . - (C)^2}$$

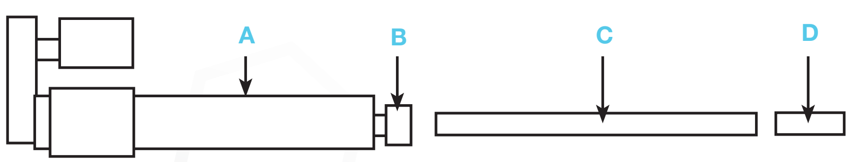
Tubing and Profile Extrusion

Procedure

The process for extruding profiles is shown schematically in **Figure 11.** TPU grades 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 takeup. After the takeup, the dimensioned profile is either cut to length or reeled as required.

Figure 11
Profile Extrusions Line
(Plan View).

A - **Extruder**
B - **Die Holder**
C - **Cooling Trough**
D - **Takeup**

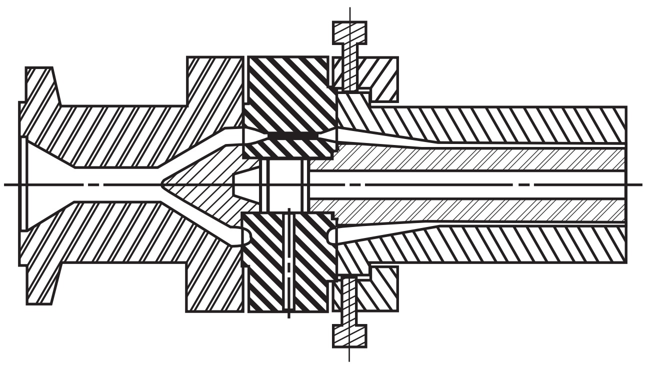


Equipment

Dies

For best results, dies should be highly streamlined and well-polished to prevent hangup. 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 2½" through 4½" extruders. **Figure 12** represents a typical die for extruding tubing.

Figure 12 Tubing Die for Single-Screw Extruder.



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 and Takeup

Profiles of TPU 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 takeoff. 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 precooling of the melt prior to entering the vacuum tank, have been used successfully to size tubing.

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Troubleshooting Guide

Here are some typical extrusion problems and several possible causes for each.

Common Problems	Possible Causes
Surging	• High moisture content • Die pressure too low • Rear barrel temperature too high/too low • 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 too shallow • Warm/Hot feed throat • Material bridging in feed throat
Bubbles (localized in sections, appearing sporadically)	• Localized hot spot in die • Material buildup in die • Improper screw design • Contamination in material
Bubbles (uniformly distributed)	• High moisture content • Melt temperature too high • Improper screw design (excessive shear) • Incompatible additive • Die temperature too high
Rough Surface	• 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
Cloudy or Hazy Particles in Otherwise Clear Extrusion	• Incompletely melted pellets • Annealed TPU “slough off” from stagnant TPU in extruder barrel, die, screw. Most commonly seen when extruding hard TPU grades or when extruder is not purged at end of a TPU run
Melt Fracture	• Metering depth too shallow • Metering depth too deep • Feed insufficient • Die land too short • Rate too high

Troubleshooting Guide (Continued)

Here are some typical extrusion problems and several possible causes for each.

Common Problems	Possible Causes
Blocking or Tacky Surface	• Melt temperature too high • Cooling takeup too short • Output excessive • Cooling water or air too cold (polyether type)
Flow Lines	• Melt temperature too high • Improper screw design • Extruder output excessive • Poor mixing • Backpressure too low • Dirty extruder or die • Extruder surging
Die Lines	• High moisture content • Die temperature too hot, too cold or not uniform • Melt temperature too low • Material buildup in die
Bridging in Feed Zone	• Screw overheated • Rear zone temperature too high • Screw speed too low • Poor shutdown procedure • Hopper dryer temperature too high
Carbon Specks	• Dirty equipment • Improper resin handling • Extruder run dry at shutdown and not cooled promptly
Poor Gauge Control	• Extruder surging • Takeoff variable • Temperature control inadequate • High moisture content

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Troubleshooting Specific Extrusion Options

Here are some typical extrusion problems and several possible causes for each.

Common Problems	Possible Causes
Tubing	
Tubing Dragging on Sizing Rings	• Do not use sizing rings to control O.D. of tubing on materials softer than 50–55D; tubing should be via “free extrusion” with a vacuum chamber to maintain roundness (using low vacuum or internal low pressure)
Droplets or Lumps Appearing on I.D. of Tubing	• Mandrel and/or die temperature too high • Contamination
Tube Sagging Between Die and Cooling Trough	• Melt temperature too high
Tubing 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 nonblocking rolls to keep extrudate submerged in cooling bath
Blown Film	
Poor Bubble Strength	• Melt temperature too high • Line speed too fast • Inadequate cooling • Moisture content too high
Blocking	• Nip rolls too low (too close to die); nip roll pressure too high • Melt temperature too high • Line speed too fast • Inadequate cooling • Material requires additional slip agent (different TPU grade or more masterbatch) • Moisture content too high
Sheet Extrusion Cast Film	
Lines Perpendicular to Flow	• Material sticking to roll – decrease melt temperature/decrease roll temperature/ slow roller speed
Plate-Out on Roll	• Poor or nonuniform contact on chill roll • Insufficient roll pressure • Nonuniform gauge
Poor Gloss or Transparency	• Increase melt temperature • Increase cooling
Blocking	• Line speed too high • Melt temperature too high • Material requires slip additive (or additional) • Top roll temperature too high

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 speciality producer of performance coatings and other unique products for apparel. Teaming with Lubrizol simplifies a complex global supply chain.

Global Locations

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