Tenite™ cellulosic plastics— Film and sheet extrusion

Tenite™ cellulosic plastics are widely used in the extrusion of film and sheeting. As plastic film and sheet use increases, plastic processors and product designers encounter an increasing number of opportunities for Tenite cellulosic plastics to meet the changing demands of today's markets.

This technical publication discusses extrusion of Tenite acetate, Tenite butyrate, and Tenite propionate into flat film and sheeting products.

Physical properties of Tenite cellulosic plastics supplied for film and sheet extrusion and other information that is used to specify these plastics for various applications are contained in Eastman publication PPC-100, *Tenite™ cellulosic plastics,* and in data sheets.

Tenite acetate, butyrate, and propionate

Tenite cellulosic products are thermoplastic in nature, which means they can be repeatedly softened and extruded by application of heat and pressure. Most references to these materials in the text will be by generic designation—acetate, butyrate, and propionate.

Tenite cellulosic plastics for extrusion are supplied as 3.2-mm (⅛-in.) pellets. Pellet uniformity is controlled to assure an accurate weight-to-volume ratio. The specific gravity of acetate is about 1.3, whereas for butyrate and propionate, it's approximately 1.2. Consequently, the product yield obtained with butyrate and propionate is about 6% greater than with acetate. All Eastman cellulosics are supplied in a variety of formulas and flows to meet special processing conditions or specific physical property requirements in the finished product.

Choice of material

The selection of a plastic is governed by the properties required in the finished product and the process by which the product will be manufactured. Tenite cellulosic plastics, in their various formulas and flows, permit choices that influence processability and physical properties of the finished product. When a new application is being considered, an Eastman field sales representative and the technical service staff in Eastman's Technical Service and Development Laboratory are available to suggest formula and flow information for initial trials. Always consult an Eastman representative if specific processing characteristics or physical properties are required.

This publication discusses some of the factors that may influence your choice of Tenite cellulosic plastic.

When selecting a Tenite cellulosic, your choice will generally be based on a combination of properties rather than on any one outstanding characteristic. Eastman cellulosic plastics provide a versatile combination of properties, including transparency and/or colorability, toughness, stiffness, and good processability. Another major benefit of Tenite cellulosics is the ease with which they can be postfinished in operations that include cutting, machining, drilling, cementing, painting, hot stamping, and polishing by solvent vapors.

Butyrate and propionate are often preferred to acetate when exceptional processing ease is a factor, when dimensional stability under severe conditions (e.g., high UV, high humidity) is important, or when some combination of these and other characteristics are desired.

Butyrate is usually preferable to propionate when superior weatherability and good dimensional stability are required or when very soft flows (not offered in propionate) are specified.

Propionate is usually preferable to butyrate when greater hardness, tensile strength, and stiffness are required. It is often selected when less residual odor in the finished part is important.

Acetate has better overall chemical resistance properties than either butyrate or propionate. Certain acetate formulas and flows also offer greater surface hardness, higher tensile strength, and more stiffness than either butyrate or propionate or most competitive plastics.

Plastics made from wood pulp—
a renewable resource

Table 1. Tenite plastics

Plastic	Formula	Flow	Percentage of plasticizer
Tenite acetate	105	H3	23%
Tenite butyrate	513	MH	8%
Tenite propionate	360	H2 or H3	9% and 12%, respectively

Choice of formula

Acetate, butyrate, and propionate differ in the cellulose esters from which they are manufactured. Several formulations are available for each plastic—each based on the use of different plasticizers. Derivative formulas contain the same plasticizer as the basic formula, but they contain other additives that affect performance characteristics. Some frequently used additives are ultraviolet inhibitors, lubricants, and odor inhibitors.

Choice of flow or percentage of plasticizer

Flow designation is based on the temperature at which material will flow a certain distance through a specified orifice at a known pressure. In any formula, the flow is governed by the plasticizer (PZ) content. A cellulosic containing a lower amount of PZ has a harder surface, higher heat resistance, greater rigidity, higher tensile strength, and better dimensional stability; conversely, higher levels of PZ give greater impact strength and are less affected by moisture absorption.

The formulas and flows listed in Table 1 represent a good balance of processability and physical properties. When physical property requirements are not specified, these formulas and flows are often suggested for initial trials.

Our technical data sheets show the old flow designation and the corresponding percentage of PZ for each formula. Orders produced by the percentage of PZ result in less batch-to-batch variation, which gives a more consistent product. Therefore, we suggest entering sample or trial orders by percentage of PZ rather than according to the old flow designations.

Choice of color

Tenite cellulosic plastics are available in natural, clear, and selected ambers, smokes, and blacks.

Color concentrates and other additives

Tenite acetate, butyrate, and propionate are also available in color concentrates, with letdown ratios of 10:1, 20:1, or higher. These color concentrates are blended with natural clear acetate, butyrate, or propionate by the molder. This can be done either by tumble blending or by automatic metering devices.

Use of regrind

Neither process efficiency nor product quality will normally be affected by using a moderate amount of regrind (i.e., 20% or 30%) in a cellulosic production operation. To minimize contamination, a closed conveying and regrinding system is suggested for scrap handling.

Drying cellulosic plastics

Cellulosic plastics absorb moisture, possibly reaching a level of 2% to 3%. Therefore, they always need to be dried before processing. Acetate absorbs moisture more rapidly than either butyrate or propionate and also reaches a higher equilibrium moisture content. The water absorption potential for all three plastics increases with temperature. Both the water absorption rate and the equilibrium moisture level increase as atmospheric temperature and/or humidity increase.

Excessive moisture in cellulosic plastics will often cause surging problems during extrusion and surface imperfections in finished products. The moisture level should be reduced to about 0.2% for good processability and surface finish; it should be as low as 0.03% to prevent bubbles in thick sheet products. A target moisture level below 0.03% will generally ensure good processability in all applications.

Drying conditions

Dry air, temperature, and time are all important considerations when drying cellulosics.

Dry air. The drying process is accomplished by transferring moisture from wet pellets to dry, heated air. Use of dry process air can ensure effective drying of cellulosic materials with minimal residence time. A closed-circuit, desiccant drying system capable of maintaining the process air dew point from –30° to –40°C (–20° to –40°F) is suggested for drying throughout the year. Such a system is unaffected by seasonal changes in ambient conditions. If the proper temperature and dwell time are used, an airflow through the drying hopper of 0.06 m^3/min/kg (1 cfm/lb/h) throughput is normally sufficient for drying cellulose ester plastics.

Temperature. In many cellulosic operations, 65°C (150°F) is considered a typical drying temperature, although the softer flows sometimes require settings as low as 55°C (130°F). Dryers can be regulated to 85°C (185°F) and higher for harder flows, but temperatures above 95°C (200°F) are never recommended for cellulosics.

Time. The drying hopper must be large enough to permit the specified dwell time for effective drying. Typical drying times shown in Table 2 will normally be satisfactory for a temperature of 70°C (160°F). Some extrusion operations require more drying time, whereas some give satisfactory results with less time. For a complete discussion of drying cellulosic plastics, request Eastman's publication SP-TRS-10164, *Drying Tenite™ cellulosic plastics.*

Table 2. Typical drying times for cellulose ester plastics

Plastic	Drying time
Tenite acetate	3–8 hr
Tenite butyrate	2–8 hr
Tenite propionate	2–8 hr

Extrusion

During extrusion, dry cellulosic pellets are gravity-fed through the extruder hopper and into the rear end of the screw. They are then conveyed forward by the screw into the heated cylinder.

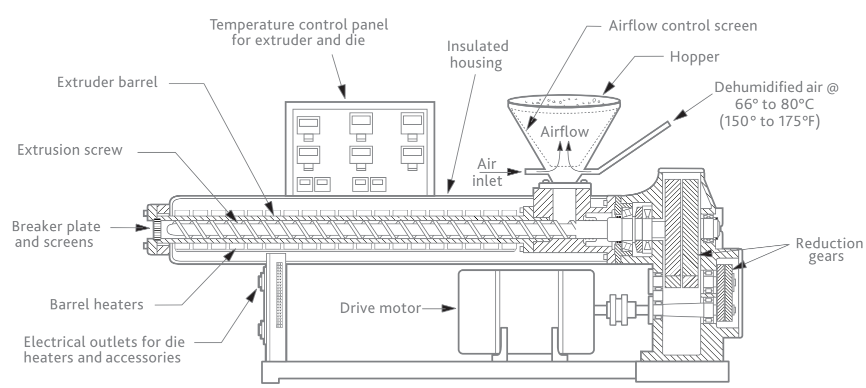
The temperature of the extruder barrel is maintained by controlled electrical-resistance heaters that are divided into several zones along the length of the barrel.

As the material is conveyed forward by the screw, it absorbs heat from the cylinder wall. Rotation of the screw mixes the melting material and provides additional shear heat to the melt and pellets. The combined melting and mixing action of a properly designed screw will ensure an extrudate of uniform temperature.

As the material proceeds toward the discharge end of the extruder, the screw depth decreases to maximize the melting and pumping effectiveness of the extruder. The discharge end of the extruder is provided with a gate for bolting the die to the extruder. The breaker plate, located in the gate, is a steel plate with many holes drilled in the direction of material flow. A set of small-mesh screens located on the upstream side of the breaker plate filter out foreign particles. If additional filtration area is needed, a commercially available device for changing the screen pack can be located between the gate and the extrusion die.

The throughput of an extruder depends primarily on the revolutions per minute (rpm) and the diameter of the cylinder. In general, the optimum size of the extruder depends on the specifications of the sheet (thickness and width) to be produced and the poundage throughput required. A custom sheet extruder might typically require an arrangement of the extruder and screw that provides maximum flexibility over a wide product range as opposed to equipment that would be used for high-poundage production of a single product.

Figure 1. Typical extruder



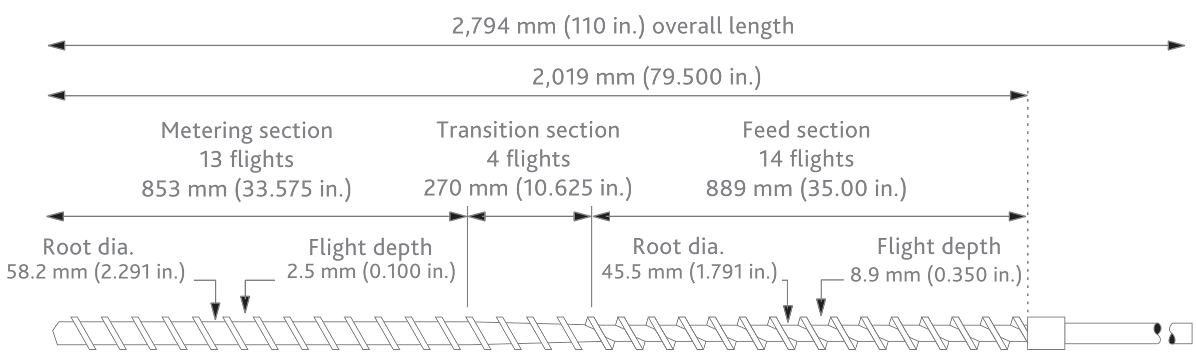
Screw design considerations

Several screw designs can be used in the extrusion of Tenite™ cellulosic plastics. The best design takes into consideration the expected throughput rate, screw speed, and particular formulation. A theoretical design based only on rheological properties can result in a screw well suited for an application, but fine-tuning may ultimately require actual extrusion trials.

Figure 2 is a drawing of a square-pitch, single-flight, 63.5-mm (2.5-in.), 30:1 L/D extrusion screw used successfully in Eastman's Technical Service Laboratory for a number of Tenite cellulosic products. Important considerations in screw design are feed length (number of flights) and depth (inches), the transition (compression) length, the metering length and depth, and the total functional length of the screw. Exact dimensioning of extrusion screws varies according to the specific rheological properties of various plastics.

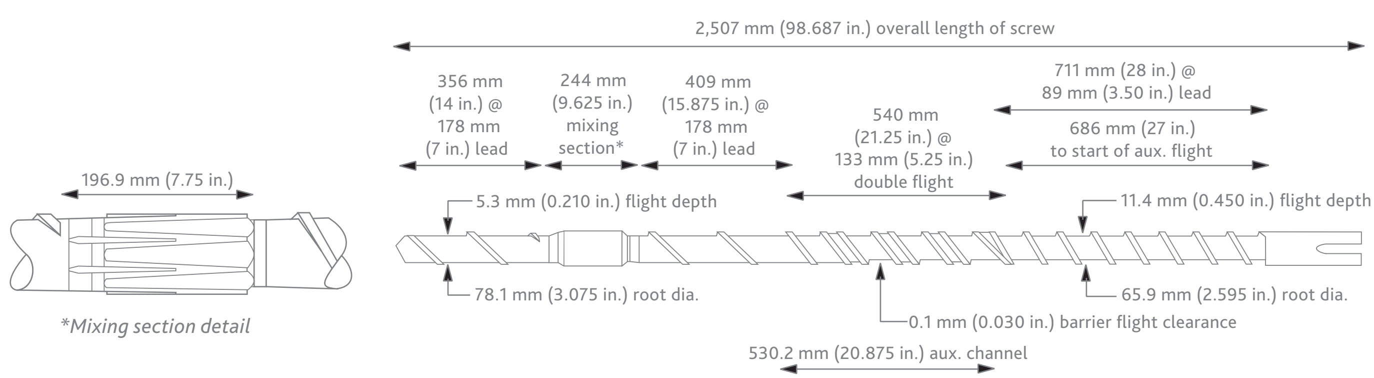
The barrier screw shown in Figure 3 illustrates a rather drastic departure from the more traditional single-flight, square-pitch screw. A screw of this type segregates the melt pool from the unmelted bed of pellets and retains an effective shear action until the melt is delivered to the metering stage. This screw design permits somewhat higher output and better mixing but typically results in higher melt temperatures than the design shown in Figure 2. The screw is available from the Feed Screws Division of New Castle Industries in New Castle, Pennsylvania, U.S.A.

Figure 2. General screw construction



63.5 mm (2.5 in.) diameter—30:1 L/D screw

Figure 3. Barrier screw



**Mixing section detail*

Sheet extrusion die

Several commercial manufacturers can be consulted when the appropriate die for cellulosic film and sheet extrusion is being considered. The die should be carefully chosen, because it directly influences sheeting quality. The internal contours of the die should be smooth without abrupt edges, stagnation points, or blind spaces. The distribution channel should be designed to ensure uniform output along the entire die length.

The coat-hanger manifold flex lip die is commonly used for cellulosic film and sheet extrusion. Typical die configurations for film and sheet extrusion are illustrated in Figures 4 and 5.

Sheet dies. The extrusion die opening should be set about 25% greater than the desired sheeting thickness to compensate for swell (pressure relief) and drawdown. A range of sheet thicknesses can be produced from one die opening, and it is therefore possible to avoid resetting the die when the size changes. Sheeting produced with higher amounts of drawdown, however, will exhibit higher shrinkage on reheating.

Even when die lips are accurately set across their entire length, variations in thickness can result from the flow pattern of the material. Minor thickness adjustments can be made by adjusting the die lips.

Sheet extrusion die lips are normally 3.8–5.1 cm (1.5–2 in.) in length for sheet thicknesses up to 0.38 cm (0.150 in.). A longer land length may be considered if the sheet thickness is to be 0.38 cm (0.150 in.) or thicker. The increased length will provide better flow control and a more uniform gauge. A land length up to about 12.7 cm (5 in.), for instance, is typical for producing sheet as thick as 0.64 cm (0.25 in.).

Film dies. Figure 4 shows a coat-hanger manifold film die with a preset opening for extrusion of 0.025 cm (0.010 in.) or less film. The flow channel and lip opening of the die are preset, and the only thickness adjustment required is that of the upper die lip. The die opening is preset to approximately 0.076 cm (0.030 in.), and all thicknesses of film are then obtained by drawdown to the desired thickness.

Figure 4. Flexible lip die for film

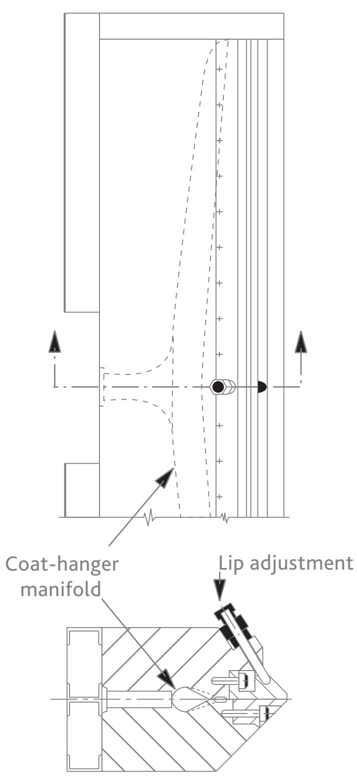
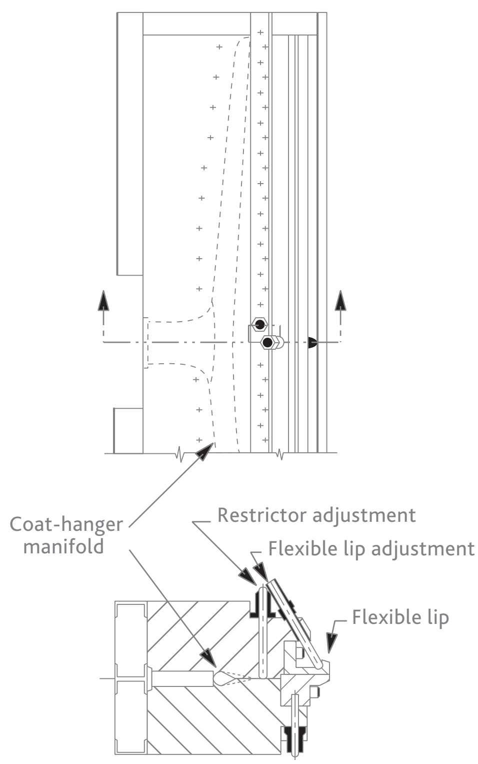


Figure 5. Flexible lip die for sheet extrusion



Chill roll stack

Typical chill rolls used in sheet extrusion consist of two- or three-roll stands, as illustrated in Figure 6. The polished chill rolls are of double shell construction to permit accurate control of the roll temperature by circulating water or other fluids such as lightweight oil. To take advantage of the good gloss and high clarity of cellulosic plastics, chill rolls are chrome plated and polished to a mirror finish (No. 1 Bright RMS). The three-chill-roll stack serves two purposes: to calender the sheet to a high-quality finish and to chill the extrudate to ambient temperature.

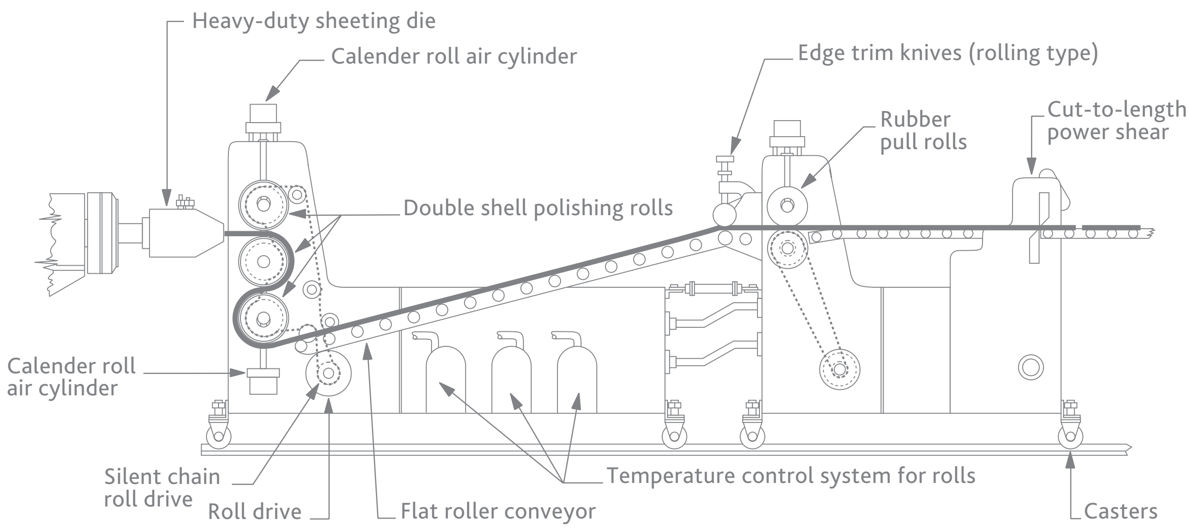
The top polishing roll is held against the sheet on a three-roll stack. The opening between the rolls is controlled by a precise adjustment mechanism, and pressure is maintained on the extrudate by air cylinders.

The die is adjusted until a small bank or bead of material about 0.32 cm (0.13 in.) in diameter is evenly distributed across the top side of the sheet at the nip between the rolls. The bottom roll, roll No. 3, can also be movable so that it can be raised to bear against the sheet. The calender roll technique is not necessarily an advantage when extruding sheeting thicknesses less than 0.010 cm (0.040 in.) because of increased machine direction strain and an accompanying loss in impact properties. Thinner film products of 0.25 mm (10 mil) or less are normally produced on a two-roll stack. Using a three-roll stack can provide better gauge control (approximately ±0.005 mm [0.002 in.]), good optical properties, and excellent surface finishes.

Heavy sheeting (≥1.02 mm [≥40 mil]) produced on a two-roll noncalendered stack can be expected to have considerably less shrinkage and greater toughness compared to similar sheeting produced on a three-roll stack. However, some you will notice some reduction in optical properties.

A pressure roll with a matte surface can be used to impart a low-gloss finish to one side of the extruded sheet. Chill roll temperatures should be maintained at the highest possible temperature at which the sheet does not stick to the roll, typically about 80°C (180°F). Roll temperatures of 50°–60°C (120°–140°F) are used with sheeting 0.51 mm (20 mil) or less in thickness.

Figure 6. Typical sheet extrusion line



Processing and handling finished sheet

A set of rubber draw rolls is used to provide a low-tension pull on the sheet as it leaves the chill roll. The sheet will normally be trimmed to width with steel knives placed immediately before the rubber draw roll. Lighter-gauge sheet of 0.20 cm (0.080 in.) or less can be trimmed to width with heavy-duty, stationary blade knives; thicker sheet is usually trimmed with a rotating bed knife.

The trimmed sheet is supported by a roller conveyor to maintain flatness and then either cut to length by a shear press or wound into continuous rolls. Heavy sheeting is cut to length, interleaved with paper or film for protection, and then stacked on a flat surface until cool. Continuous thin film is wound on rolls, usually without interleaving; a protective wrapper around the finished roll is suggested.

Machine cleanup

An extruder and die may be cleaned while at elevated temperature or, if time permits, after they have cooled. Procedures for both cleaning methods follow. Before either method is used, however, the extruder and die must be purged with Tenite butyrate or Tenite propionate or some other suitable purging compound to remove all the previously used material. If it is a cellulosic process, the purging time will be minimized.

Cleaning hot equipment

After the machine has been purged and emptied, the gate can be opened and the screen pack removed.

The cylinder temperatures should be reduced to approximately 120°C (250°F) by turning on the blowers while the screw continues to turn slowly. When the cylinder temperature is between 105°C (225°F) and 120°C (250°F), the screw should be removed. Cellulosic material remaining on the screw can be removed by directing a stream of compressed air on the area while pulling the residue away with needle-nose pliers. If a thermoplastic material other than a cellulosic has been processed, a thin layer may be left on the root of the screw. It should be removed with a fine-bristle brass brush while the screw is still hot. The extruder cylinder can be cleaned by attaching an oversized flue brush to an electric drill and rotating the brush throughout the length of the cylinder. Good results can be obtained if the flue brush is attached to a 12.7-mm (0.50-in.) rod (long enough to reach through the cylinder) and driven by an electric drill motor.

After four or five passes of the brush through the cylinder, compressed air can be used to remove the remaining loose particles from the cylinder.

Cleaning cold equipment

After the machine has been purged and before cooling the equipment to ambient temperature, the die is removed from the extruder.

The extruder hopper should be emptied and the screw allowed to turn until the cylinder is empty. The gate can then be opened and the screen pack removed. The cylinder temperatures should then be reduced to about 135°C (275°F). While the screw continues to turn, a small quantity of butyrate is hand fed into the screw. This procedure assists in clearing the cylinder and screw and should be continued until the cylinder becomes too cold for further purging. The empty machine should then be cooled to ambient temperature. The screw can then be pushed out of the cylinder and the remaining particles of butyrate scraped away with a wire brush or a soft brass blade. The hopper, dryer pipelines, and air-conveying lines should then be thoroughly cleaned.

Film and sheet extrusion troubleshooting guide

Problem	Possible cause	Suggested solution
Die lines in film/sheet	Moisture in material	Dry material more thoroughly.
	Dents or scratches in die	Remove, polish, and buff die lips.
	Burned or degraded material in die	Clean the die. NOTE: Temperature of molten plastic should always be reduced to 120°–150°C (250°–300°F) before shutting extruder down or setting idle more than 3 hours.
Bubbles in sheet	Moisture in material	Dry material more thoroughly.
	Screen pack not used	Install screen pack.
Unmelts in film/sheet	Previously extruded material remaining in die or behind screens	A. Clean the die.
		B. Avoid following a hard-flow material with material of a softer flow.
		C. Tenite butyrate following Tenite acetate does not purge the machine efficiently. Machine sometimes can be purged of Tenite butyrate by following with Tenite acetate.
	Too much regrind or contaminated regrind material being used	Reduce percentage of reground material and be sure it is clean.
	Screen pack not used or screen pack damaged	Install screen pack and maintain in good condition.
Surging	Temperatures out of balance	Ordinarily, keep the die temperature a few degrees lower than temperature on front section of cylinder.
	Temperature on front section of cylinder too high	Adjust temperature. Maximum temperature on front section usually not above 205°C (400°F) for H2 flow.
	Land length in die too short	Increase land length.
	Material entering feed throat at uneven temperature	Provide continuous dryer or hopper dryer heated with air.
	Uneven discharge of material from screw	Change temperature profile.
	Temperature at feed throat too high	Use circulating water to maintain temperature @ 21°–32°C (70°–90°F).
	Mesh of screens in screen pack too large	Use finer-mesh screens.
	Too much clearance between screw and cylinder wall	Build up screw or reline cylinder.
	Improper screw-compression ratio	Change screw.
Surface blushes on sheet	Die too cold	A. Increase die temperature.
		B. Increase temperature on front section of cylinder.
	Cold air blowing on die	Enclose die and the pullout rolls as protection from cold air.
	Die lips out of adjustment	Readjust for better thickness.
	In case of Tenite butyrate, air supplied to cooling jets too cold	Increase air-heater temperature.
	Too much air to cooling jets	Reduce amount of air to jets.

Film and sheet extrusion troubleshooting guide *(continued)*

Problem	Possible cause	Suggested solution
Sheet surface rough on one side	Die lips on side that shows roughness	Adjust to align die lips exactly flush on faces.
Small dimples in sheet	Dirt adhering to pullout rolls	Clean rolls with dry cloth or use metal polish.
Edges of sheet blushed	End plates of die too cold	Increase temperature on end plates.
	Die lips out of adjustment ends	Adjust die lips.
Deep scratch in sheet surface	Hard particle of foreign material lodged in die lips	A. Clean the die.
		B. Mesh of screens too large or damaged. Examine and replace if necessary.
	Burr on die lips	Remove, polish, and buff die lips.
Chatter marks or ripples in film/sheet	Product emerging from die too hot	Reduce die temperature.
	Draft of room air blowing on sheet	Provide enclosure around die and pullout rolls.
	Vibration of extrusion machine or other machines operating nearby	Tighten all floor bolts on extrusion machine and determine whether drive is running smoothly. (Extrusion machine must be mounted on solid foundation and free from building vibrations.)
Sheet wrinkles or does not lie flat	Air around sheet too cold	Keep doors closed and eliminate drafts.
	Pullout rolls too cold	Increase temperature of pullout rolls.
Sheet brittle and cracking at trimmers or wind-up	Tension rolls too cold	Do not use cold water on rolls. Run rolls at room temperature or heat slightly.
	Temperature of operating area too low	Keep operating area temperature at 21°C (70°F) or higher.
Die runs too hot/slow to cool	Screw running too fast	Reduce speed of screw.
Center of sheet has etched appearance	Hot plasticizer fumes marring sheet surface	Install hood around die to conduct fumes away by convection.
Variation in thickness across film/sheet	Die lips out of adjustment	Adjust die lips.
	Die temperatures not in balance	Ordinarily, maintain the front part of the die at a slightly lower temperature than the back section.
	Land length too short	Increase land length.
	Material channeling through die	A. Restrict flow of material before it reaches die lips.
		B. Install screen pack to increase back pressure.
Excessive shrinkage of sheet during subsequent forming operations	Sheet extruded too cold, inducing strains	Extrude sheet at higher temperature.
	Too much drawdown in extrusion, inducing strains	A. Reduce drawdown by lowering speed of takeoff.
		B. Use die lips with prescribed opening and land for sheet thickness desired.

Note: *The information provided in this publication is intended as guidance for a typical production operation. Differences in manufacturing processes, equipment, and personnel may require the user to modify the guidelines accordingly. It is the responsibility of the users to determine for themselves whether these guidelines are safe and technically suitable for their specific operations.*

For more information, contact your Eastman representative or go to eastman.com.

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