Processing Guide
Extrusion thermoforming PLA for cold applications

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INTRODUCTION

This processing guide outlines the process of extruding and thermoforming PLA for cold-use applications (below 50°C) like cold drinking cups, clamshells, and food trays.

Polylactic Acid (PLA) is a GMO-free, biobased thermoplastic polymer derived from annually renewable resources. It is certified as industrially compostable under the EN 13432 and ASTM D6400 standards. Luminy® PLA can be processed using conventional extrusion and thermoforming technologies to produce thermoformed products.

STORAGE CONDITIONS

It is recommended to store PLA polymers and compounds in their original, sealed moisture-barrier packaging at temperatures below 50°C. Storage in direct sunlight should be avoided. The supplied Luminy® PLA pellets are typically semi-crystalline.

PLA RESIN PROPERTIES

The following PLA grade is recommended for extrusion thermoforming for cold applications.

PLA grade	Luminy® PLA LX175	
Measure	**Unit**	**value**
Density	g/cm3	1.24
MFI, 210°C/2,16kg	g/10min	6
Glass transition temperature	°C	60
Melting temperature	°C	155

Table 1: Recommended grade for extrusion thermoforming for cold applications.

ADDITIVES

PLA-based additive masterbatches can be dry blended with PLA to enhance the extrusion and thermoforming process or to modify the properties of the final products. Table 2 provides an overview of potential additives that can be used in combination with PLA and their suppliers.

Type	Functionality	Recommended loading	Suppliers
slip / anti-block	de-nesting	1-5%	Sukano Plastikakritis Granula Avient
Impact modifier	toughness improvement	1-5%	Sukano Plastikakritis Granula Avient
color	color	1-5%	Plastikakritis Granula Avient

Table 2: Masterbatches for extrusion thermoforming of PLA

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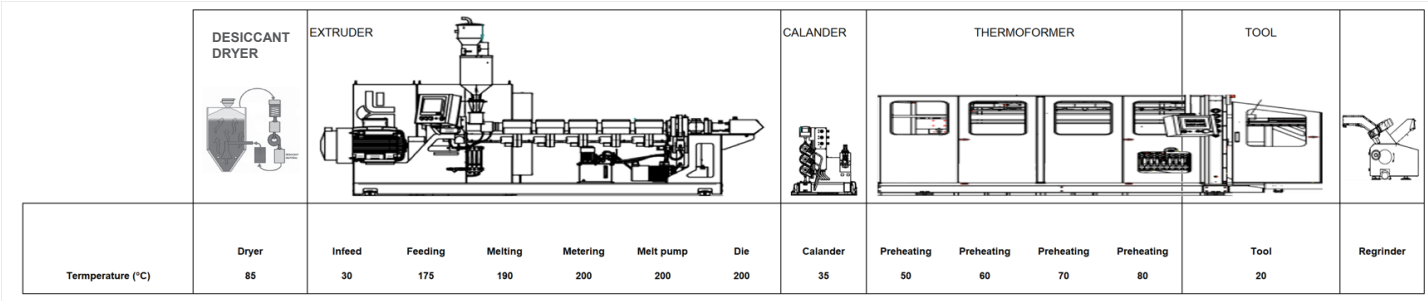
The general process and processing temperatures of extrusion thermoforming of PLA for cold applications are shown in Figure 1.
The process can be carried out two ways:
1. Inline, where the article is thermoformed immediately after sheet extrusion.
2. Offline, where roll stock is extruded and stored, then later thermoformed into the article.



	Dryer	Infeed	Feeding	Melting	Metering	Melt pump	Die	Calander	Preheating	Preheating	Preheating	Preheating	Tool	Regrinder
Termperature (°C)	85	30	175	190	200	200	200	35	50	60	70	80	20	

Figure 1: PLA extrusion thermoforming process for cold applications.

DRYING

Luminy® PLA resins are supplied in aluminum-lined moisture-barrier packaging with a maximum moisture content of 400 ppm. Before melt processing, it is recommended to reduce the moisture content to below 250 ppm, ideally to 100 ppm. Excess moisture can cause hydrolysis of the PLA during melt processing, leading to reduced processing stability and diminished mechanical performance in the final product.

Luminy® PLA resins can be dried using most conventional drying systems. The preferred method is a desiccant hot air dryer, though a vacuum drying oven is also an option. It is highly recommended to verify the moisture content after drying using methods such as Karl-Fischer or Brabender Aquatrac. If additives are used, their moisture content should also be checked and dried if necessary.

Dried PLA should be processed immediately after drying, ideally in an inert (nitrogen) atmosphere to prevent moisture absorption. Starting at a moisture content of 100 ppm, the critical level of 250 ppm can be reached within just 15 minutes of exposure to atmospheric conditions. (Figure 2).

The packaging should remain sealed until use, and any unused material should be resealed immediately. To prevent moisture uptake, it is recommended to use a closed system from the dryer to the feeder, install the dryer on top of the feeder, or apply a dry nitrogen blanket in the feeder and extruder throat. Typical PLA drying conditions using a desiccant hot air dryer are shown in Table 3.

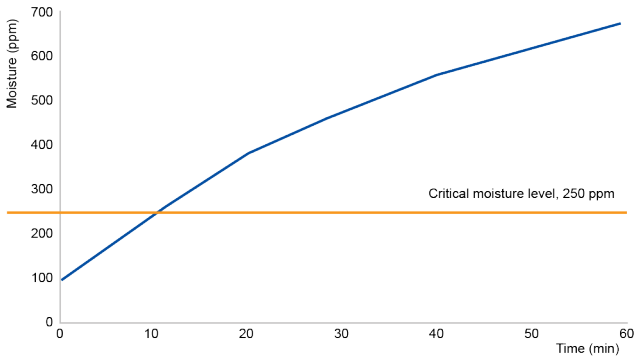


Figure 2: Moisture take-up curve PLA polymer

PLA grade	Pre-crystallized standard PLA (LX175)
Drying time	4-6 hours
Air temperature	85°C
Air dew point	< -40°C

Table 3: Drying conditions for Luminy PLA

EXTRUSION

This section provides a guideline for the successful extrusion of PLA-based sheets in the thickness range of 0.2-1.0mm. Extrusion can be performed on conventional single-screw and twin-screw extruders. Since PLA degradation products are corrosive, it is highly recommended that parts in contact with molten polymer be made of stainless steel. To prevent PLA degradation, avoid leaving PLA in the extruder and auxiliary equipment at high temperatures for extended periods

Start-up and shutdown

Before introducing Luminy® PLA, ensure the extrusion equipment is thoroughly cleaned and purged to prevent cross-contamination. That includes cleaning the feeding and blending equipment to remove dust and contaminants before the materials and additives enter the extruder. The purging procedures below are recommended for removing other polymers when processing PLA.

1. Check if there are residual polymers from previous runs present in the barrel of the machine. Set the machine temperature to the processing temperature of either the previously used polymer or PLA, whichever is higher, to ensure the machine starts up without non-molten material.
2. Purge based on previous polymer:
   a. Polyolefins (e.g., PS, PP): Purge with a polyolefin of similar MFI to PLA or a purging compound (e.g., ASAclean, Dyna-Purge), then follow with PLA.
   b. PET: If PET's processing temperature is incompatible with PLA, use a low MFI resin (e.g., PETg, PP) at PET's operating temperature.
3. Adjust the barrel temperature to the required temperature for PLA.
4. Check that the processed material is free of contamination before starting production.
5. After completing the run, purge the system with a purging compound to remove residual PLA for five times the average residence time. Refer to the purging compound supplier's recommendations for specific conditions.

After completing the run, remove all PLA from the system, as it can degrade into lactic acid over time, which may cause corrosion of the equipment.

Sheet extrusion.

Sheet extrusion can be done on conventional extrusion equipment, equipped with a general purpose single screw extruder with L/D ratios between 24 and 32. To avoid cross-contamination, the extruder and auxiliary equipment must be purged and cleaned before and after PLA extrusion.

Horizontal, inclined, and vertical roll stacks with highly polished chrome plating have been successfully used. The roll temperatures should be individually controlled and set within the range of 25-50°C.

Air entrapment between the sheet and the chill roll can cause excessive residual lactide buildup on the chill rolls,resulting in poor sheet quality. To minimize this buildup, use techniques such as electrostatic pinning or vacuum, adjust the nip gap, ensure uniform sheet thickness across the width, and optimize chill roll temperatures. However, be cautious: excessively high roll temperatures can cause the film to stick to the chill roll, also leading to poor sheet quality.

Typical extruder conditions for PLA sheet/film extrusion are shown in Table 4.

Parameter	Setting [°C]
Resin intake	20-40
Melt zone	170-190
Mixing & Conveying	190-210
Melt pump	190-210
Die	190-210
Chill roll	25-50

Table 4: Recommended processing temperatures for sheet extrusion of Luminy® PLA.

Edge trimming:
PLA is a stiff material, so preventive measures should be taken to minimize the risk of cuts from sharp edges for operators. Edge trim is preferably slit with rotary shear knives. The use of razor knives can only be considered if the sheet is locally heated to 40-60°C. Trimming cold sheets with razor knives likely will lead to many web breaks and is therefore not recommended.

Static eliminator:
To prevent dust and contamination, as well as to avoid static shocks to operators, eliminating static electricity is recommended. Effective measures include using a bar-type static eliminator to distribute ionized air over the operation or employing well-grounded anti-static copper tinsel.

ROLL STOCK STORAGE:

Roll stock made from Luminy® PLA resin should be stored at temperatures below 40°C. Temperatures above this can cause roll blocking and, depending on relative humidity, may lead to degradation and loss of physical properties. Pre-drying of roll stock to prevent moisture-related defects is not required.

THERMOFORMING:

This section provides a guideline for the successful thermoforming of PLA-based articles for cold-use applications like cold drinking cups, clamshells, and food trays. Thermoforming can be performed on conventional thermoforming equipment at a forming temperature between 80 and 100°C.

Sheet handling:
It is not necessary to preheat the sheet before entering the heating section.
Luminy® PLA is a relatively brittle material at ambient conditions. Therefore precaution measures should be considered when thermoforming PLA.

- Edge pre-heating of the sheet to a temperature of 60-80°C is recommended to prevent the sheet from cracking when pinned into the transportation chain.
- Good tension control throughout the whole thermoforming process is mandatory. Sudden tension changes can result in web breaks.
- Sharp path radii of the sheet throughout the thermoforming process should be avoided to minimize web breaks.

Sheet heating:

Conventional heaters can be used to heat the PLA above its softening point of 60°C. This is lower than most other conventional plastics used in thermoforming, therefore the ovens typically set at a lower temperature targeting a sheet temperature of 80-100°C at the end of the oven.

Sheet forming

Conventional forming technologies, such as vacuum forming or pressure forming can be used to form the sheet into its desired shape. For deeper drawn articles, such as trays and cups, plug assist forming is recommended to achieve optimal material distribution.

The forming of the sheet is typically performed in a temperature-controlled aluminum mold set at a temperature well below the softening temperature of PLA. The recommended mold temperature is 20-40°C.

The shrinkage of PLA is comparable to other amorphous resins such as PS and aPET, which enables the use of these mold and trim tools for PLA.

Trimming:

PLA is a hard and brittle material. It is therefore recommended to trim the part when the sheet is still above its softening temperature of 60°C.

PLA runs on machines equipped with cut-in-place (tilt) molds and on combined forming and cutting machines.
Steel-rule and matched-metal dies can be used for trimming PLA.
Typical thermoforming conditions for PLA sheets are shown in the Table 5.

Parameter	Setting [°C]
Pre-heating	Not required
Sheet temperature	80-100
Mold temperature	20-40

Table 5: Recommended processing temperatures for thermoforming Luminy® PLA.

REGRINDING:

The obtained edge trim and skeleton waste during the extrusion and thermoforming process can be regrinded for reprocessing. Ensure that the regrind system has been cleaned to prevent cross-contamination and that the temperature of the incoming sheet is less than 40°C.

RECYCLING:

PLA edge trim and skeleton waste can be regrinded and recycled into new sheet. Precaution should be taken in the handling of the recycle stream. When PLA is (re)processed at the recommended processing conditions, hydrolysis is the main mechanism for degradation, which will lead to molecular weight loss and consequently loss of mechanical properties. Proper drying of the regrind along with virgin resin is mandatory to minimize the effect of the hydrolytic degradation during melt processing. Sheets containing up to 50% properly handled recycle have been successfully processed into new sheets.

The obtained edge trim and skeleton waste during the extrusion and thermoforming process will be in the amorphous form. The amorphous regrind can either be recrystallized before reprocessing into sheets or used as such.

However, it is recommended to recrystallize the amorphous regrind to prevent agglomeration during mixing with virgin hot dried PLA resin or at the extruder intake section.

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Crystallization can be performed using conventional crystallization equipment such as infrared rotary drum systems or fixed bed crystallizers equipped with an agitator. The optimum crystallization temperature of PLA lies between 90-110°C and typically within 30 minutes the PLA has achieved a degree of crystallinity losing its stickiness.

Be aware that the Luminy® LX975 and Luminy® LX930 are amorphous PLAs and cannot be crystallized.

Methods for reprocessing either amorphous or re-crystallized regrind is described below.

Reprocessing amorphous PLA regrind:
Similar to virgin PLA resins, amorphous PLA regrind should be processed at a moisture level not higher than 250ppm, and needs to be pre-dried in a desiccant hot air dryer. The drying temperature should not exceed 40°C to prevent agglomeration in the drier. The required drying time will depend on the moisture content of the regrind. If the regrind is exposed for a longer period to ambient conditions, a drying time of at least 24 hours is recommended.

When mixing regrind with other materials, such as virgin resin, ensure that the temperature is less than 50°C to prevent agglomeration.

The extruder intake and 1-3 diameter screw length should be actively cooled to prevent sticking of the regrind to the screw. If sticking to the screw happens, it will lead to surging and ultimately a complete blocking of resin feed into the extruder.

Reprocessing recrystallized PLA regrind:
Similar to virgin PLA resins, recrystallized PLA regrind should be processed at a moisture level not higher than 250ppm, and needs to be pre-dried in a desiccant hot air dryer.

Drying can be performed in a desiccant hot air dryer at 85°C. The required drying time will depend on the moisture content of the regrind. Typical drying times between 4-6 hours are sufficient to reduce the moisture content to less than 250ppm.