# Processing Guide
## Injection molding of standard & high heat PLA compounds

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**PROCESSING GUIDE**
**INJECTION MOLDING OF STANDARD AND HIGH HEAT PLA COMPOUNDS**

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### INTRODUCTION

This processing guide describes the handling and injection molding of standard PLA and high heat PLA compounds. Injection molding is a process of melting the PLA polymer or PLA compound, injecting it under high pressure into a mold and solidifying it until a stable part is achieved. Standard PLA compounds will result in an amorphous structure whereas high heat PLA compounds can result in a semi-crystalline structure.

High heat PLA can be obtained by combining PLA and PDLA homopolymers. Compared to standard PLA, these homopolymers have higher melting points and an increased rate of crystallization. As a result, compounds containing the homopolymers are suitable for the production of semi-crystalline parts, which exhibit a higher temperature resistance.

The injection molding recommendations are applicable to standard PLA as well as high heat PLA compounds, taking into account that a different mold temperature should be used.

As injection molding is a general processing technology with a lot of possibilities in terms of applications and material formulations, the information that is given in this processing guide only serves as a starting point. Optimization of the process is recommended to find the optimal process conditions to injection mold the desired part. To validate that the produced part is meeting customer requirements, testing of the molded products is recommended.

### STORAGE CONDITIONS

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

### TYPICAL PLA COMPOUND PROPERTIES

Table 1 shows typical properties for compounds based on Luminy PLA that can be used for injection molding.

| Property | Unit | Compound A[1] General purpose | Compound B[1] Mineral filled | Compound C[1] Impact modified | Compound K[1, 2] Compostable |
|---|---|---|---|---|---|
| Density | g/cm³ | 1.25 | 1.37 | 1.27 | 1.29 |
| Clarity | Yes/No | No | No | No | No |
| MFI (210ºC/2.16kg) | g/10 min | 12 | 10 | 6 | 8 |
| Pre-drying | Yes/No | Yes | Yes | Yes | Yes |
| Mold temperature | ºC | 90-100 | 90-100 | 90-100 | 90-100 |
| Melt temperature | ºC | 190-220 | 190-220 | 190-220 | 190-220 |
| Tensile modulus | MPa | 3600 | 5500 | 4000 | 3600 |
| Tensile strength | MPa | 60 | 60 | 40 | 50 |
| Strain at break | % | <5 | <5 | 47 | 8 |
| HDT-B, 0.45MPa flatwise | ºC | 90 | 110 | 90 | 80 |
| Impact (Charpy notched, 23ºC) | kJ/m² | 3 | 2 | 18 | 8 |

*[1] Developmental grades, all data is preliminary. Total Corbion PLA does not commercially produce these PLA compounds.*
*[2] Compliance with EN-13432 standard to be tested for final product.*

*Table 1: Overview of high heat PLA compounds for injection molding*



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### DRYING PLA

Luminy PLA resins are supplied in sealed aluminum-lined barrier packaging with a maximum moisture content of 400 ppm. It is recommended to reduce the moisture content before melt processing to a level less than 250 ppm and preferably to 100 ppm. Moisture causes hydrolysis of the PLA homopolymer during melt processing, resulting in reduced mechanical performance in the final part.

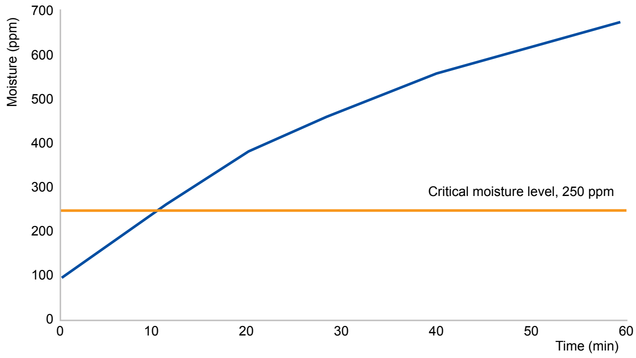

*Figure 1: Moisture take-up curve PLA homopolymer*

Luminy PLA resins can be dried using most conventional drying systems. The preferred method to dry PLA is by using a desiccant hot air dryer system. Another option is to use a vacuum drying oven. It is highly recommended to check the actual moisture content after drying, for which the Karl-Fischer or Brabender Aquatrac methods can be used. In case additives are used, it is also necessary the check the moisture content of the additives and dry them if necessary.

The dried PLA should be processed as soon as possible after drying and preferably under an inert (Nitrogen) atmosphere to prevent moisture uptake. Starting at 100ppm moisture content, the critical level of 250ppm is already reached after 15 minutes of exposure to atmospheric conditions (Figure 1).

The packaging should be kept sealed before usage and any unused material should be resealed immediately. It is recommended to have a closed system from the dryer into the feeder, a dryer installed on top of the feeder, or to apply a dry nitrogen blanket in the feeder and throat of the extruder to prevent moisture uptake. Typical PLA drying conditions using a desiccant hot air dryer are shown in table 2.

| Parameter | Amorphous PLA | Pre-crystallized standard PLA (Luminy® LX175) | Crystalline PLA homopolymers (Luminy® L105, L130, L175) |
|---|---|---|---|
| Drying time | 24 hours | 4-6 hours | 4-6 hours |
| Air temperature | 40ºC | 85ºC | 100ºC |
| Air dew point | < -40ºC | < -40ºC | < -40ºC |

*Table 2: Typical PLA drying conditions*

### START-UP AND SHUTDOWN

Before introducing Luminy PLA, the injection molding machine needs to be well cleaned and purged to prevent cross contamination. Also, make sure that the feeding and blending equipment in the material preparation steps (before the materials and additives enter the extruder) is extensively cleaned and that they are free of dust and contamination. The injection molding machine purging procedures below are recommended for removing other polymers when processing PLA.

1. Check if other polymers from previous runs are present in the barrel of the machine. To prevent starting up the machine with non-molten material, the temperature range of the machine should be set to the processing temperature of the previously used polymer or the PLA, whichever has the highest processing temperature.
2. Purge the system with a polyolefin with similar MFI to PLA, or a purging compound (e.g. ASAclean, Dyna-Purge, etc.) followed by purging with the PLA homopolymer.
3. Change the temperature of the barrel to the required temperature for PLA.
4. Check that the processed material is free of contamination before starting production.
5. At completion of the run, it is recommended to purge the system again by using a purging compound to clean the machine from remaining PLA material. Check the recommendations of the supplier of the purging material for the right conditions.

After completion of the run, PLA must be removed from the whole system. PLA can degrade over time into lactic acid causing corrosion of the equipment.

## INJECTION MOLDING MACHINE SETTINGS

Luminy PLA can be processed on conventional injection molding equipment. To prevent or reduce the degradation of PLA during processing, it is recommended to use a barrel with a content of 3-5 times the shot weight, a (general purpose) screw with an L/D ratio of at least 20:1 and – if applicable - low shear hotrunners in the mold.

Typical injection molding conditions for high heat PLA compounds are shown in Table 3.

| Parameter | Unit | Settings |
|---|---|---|
| Throat | ºC | 20-40 |
| Feed zone | ºC | 155-175 |
| Compression zone | ºC | 180-220 |
| Metering zone | ºC | 180-220 |
| Nozzle | ºC | 180-220 |
| $T_{melt}$ | ºC | 180-220 |
| $T_{mold,amorphous}$ | ºC | 20-30 |
| $T_{mold,crystalline}$ | ºC | 90-100 |
| Back pressure | Bar, specific | 50-100 |
| Screw speed | rpm | As slow as possible without influencing the cooling time |

*Table 3: Typical injection molding settings for high heat PLA compounds.*

## USING A HOT OR A COLD MOLD

Table 3 shows that different mold temperatures can be used. A cold mold is used to cool down the injected material as soon as possible, which will result in amorphous PLA end-products.

For an end-product to have a higher temperature resistance, the mold temperature should be set at 90-100°C in order to crystallize the material during cooling, which will result in a semi-crystalline PLA structure. The time required to achieve maximum crystallinity in the mold during the crystallization phase depends on the PLA formulation, mold temperature and part design, but in most cases it will be longer than the necessary time to cool down the PLA material in a cold mold. This results in longer cycle times for semi-crystalline products. Due to its semi-crystalline PLA structure, the product becomes stiff enough at 100°C to eject it from the mold without deformation. The product is still slightly flexible until it is cooled down below the PLA glass transition temperature of around 55°C.

## OPTIMIZING CYCLE TIMES

To obtain the shortest cycle time, it is essential to use the right mold temperature, especially for semi-crystalline products. It is therefore strongly recommended to measure the temperature of the mold at different places using an internal or external thermo couple. Even if the mold heater (return) temperature indicates that the temperature is in the right range, it could still be possible that the mold temperature is not correct due to heat losses. After producing the amorphous or semi-crystalline product and ejecting it from the mold, it is important to prevent deformation. Please use suitable conveyer belts and collection boxes to accomplish this.

Crystallization of PLA is a slower process than the processs of cooling down from the melt to the temperature below the glass transition



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temperature. For a thin walled product this can result in a cycle time that might be higher for crystalline products than for amorphous products. For a thicker walled product, the time to cool down the product is longer than the time needed for crystallization. In this case, the crystallization time is not the rate determining step anymore.

## MOLD DESIGN RECOMMENDATIONS

The mold used to produce parts are always optimized and fine-tuned for certain polymers. Also molds used for producing PLA parts need some attention.  First, a low shear hotrunner system should be used without dead spots in the manifold or nozzles to prevent degradation of the PLA material. An externally heated nozzle with an open channel should be used to not disturb the PLA flow though the nozzle and prevent flow lines on the product that can be caused by a torpedo in an internally heated nozzle. Figure 2 shows examples of a (16 cavity) manifold and an externally heated open nozzle.

a) b)

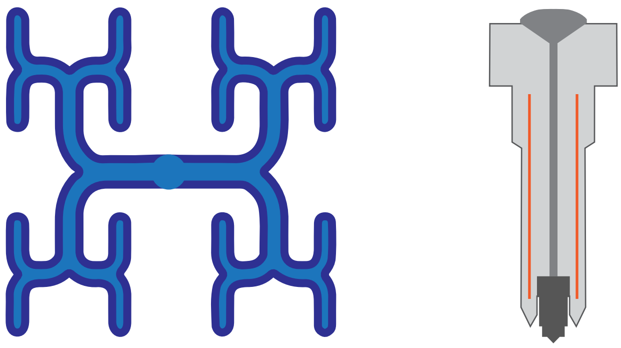

*Figure 2: (a) low shear hotrunner system without dead spots of a 16 cavity manifold; (b) externally heated open nozzle*

If a sprue is used instead of a hotrunner, please take into account that the total draft angle of the sprue must be higher than 6° to prevent sticking of the sprue at the injection side of the mold at the moment the mold opens. This reduces the maximum height of the sprue. The sprue becomes too thick otherwise and will determine the cooling/crystallization and thereby the cycle time of the process. The wall thickness of the sprue should always be less than the maximum wall thickness of the made product.

For high heat materials, PLA should be able to crystallize in the mold. Only polymers can become semi-crystalline, leaving the remaining material in the amorphous phase. This will result in a slightly flexible product at the moment it is ejected from the mold. Increasing the draft angle of the product and installing sufficient ejector pins with sufficient ejector surface will help to prevent warping of the product during ejection from the mold.

PLA is a highly viscous material that will be injected into the mold under high pressure. This often results in (minor) flash on the product if the venting is not correct. It is recommended to start with minimal venting and opening up the machine (remove steel) at the moment it is necessary. When parts of the mold are not filled or when burned PLA material can be found near the venting points this indicates that the venting is not sufficient and needs to be increased.

PLA flash can be sharp due to the stiffness of the material. The venting design should be such that venting is taking place close to the place where it is necessary, while at the same time taking into account venting in the mold is not taking place at the place where flash is not allowed.

PLA products that have a higher heat resistance than standard PLA need to crystalize in the mold, which results in more shrinkage than products made from standard PLA. This should be taken in account when designing a mold for PLA products with tight dimensional specifications. Always develop a mold in such a way, that after the first reproducible injection molding trial, steel can be removed at places where it is necessary.

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