Processing Guide for Thermoforming Articles

This information is intended for use only as a guide for the manufacture of PLA thermoformed articles. Because thermoforming incorporates a wide range of processing variables, an experimental approach may be required to achieve desired results.

1.0 Safety and Handling Precautions

All safety precautions normally followed in the handling and processing of thermoplastic sheet should be followed for sheet made from NatureWorks® PLA resins. Personal protective equipment includes gloves and clothing designed to protect against abrasions and cuts at room temperature in addition to protecting against burns at elevated temperatures.

As with most thermoplastics, thermal processing and the variability of those conditions may result in minor decomposition. A process upset that would involve PLA sheet resting in the bottom of the oven could involve thermal conditions similar to melt processing of PLA. Lactide, a non-hazardous gaseous irritant, is a minor by-product of PLA melt processing. Process area point source remediation measures such as monomer fume hoods or exhausts are typically recommended, in melt processing of PLA, to maintain the acceptable air Threshold Limit Value (TLV) for lactide of less than 5 mg/m^3.

As with any thermoplastic waste hot enough to be melted or compressed into a solid mass, hot PLA waste should be allowed to cool before being placed into any waste container to minimize fire risks.

PLA is considered non-hazardous according to DOT (US Department of Transportation) shipping regulations.

2.0 Sheet and Thermoformed Parts Storage Recommendation

PLA sheet should be stored in an environment designed to minimize moisture uptake, and in a cool place at temperatures below 40°C (105°F). It is not necessary to dry PLA sheet prior to use to obtain haze free parts. At temperatures above 40°C the sheet is susceptible to blocking and would resist unwinding. In environments above 40°C and above 50% RH, the sheet is susceptible to molecular weight breakdown and loss of physical strength.

PLA thermoformed parts should be shipped and stored in an environment that minimizes exposure to heat, moisture, and humidity; including maximum temperatures below 40°C (105°F). Clear, amorphous PLA thermoformed parts at temperatures above 40°C are susceptible to distortion. At temperatures above 40°C and above 50% RH, PLA thermoformed parts are susceptible to molecular weight breakdown and loss of physical strength.

PLA is highly polar and can retain a charged surface, if untreated. A charged surface can attract dust; but the charge can be mitigated by the use of local electrostatic eliminator bars. Protection of sheet goods with packaging material is also recommended to control dust collection on the sheet.

3.0 Sheet and Thermoformed Article Properties

Addressing Relative Toughness or Brittleness

PLA sheet is relatively brittle at room temperature. The elongation to break under tensile stress is between 4 and 8%. Good tension control during web handling is critical as sudden increases in tension during any portion of the unwind process may result in web breaks. Power driven nips at the unwind station are recommended. In addition, unwind stations and skeleton rewind stations should have web paths that minimize tight radius paths of the web. Minimum skeleton rewind radius should be 10-inches (25-cm) to insure smooth travel of the web and minimum breakage.

The toughness of PLA increases with orientation and therefore thermoformed articles are less brittle than PLA sheet, particularly in the regions that have been highly stretched during the forming operations. Experimentally, the elongation to break under tensile stress has been seen to increase from 4-8% in sheet to about 40% in the sidewall of a drinking cup. Flange or lip areas that receive less orientation tend to be more brittle than the rest of the thermoformed part.

If the sheet must be slit to size prior to thermoforming, then a rotary shear knife is required for trimming. Edge preheaters are necessary to prevent the sheet from cracking at the pins and to minimize rail chips. The edge preheaters will be set (temperature and proximity to the sheet) to warm the sheet to near 200°F (190°C). Contact heat edge preheaters would typically be set to 212°F (100°C). Non-contact heat edge preheaters would typically be set warmer than would be used with similar thickness sheet made of polystyrene or PET, and may approach the thermoforming oven set points.

Addressing Forming and Trimming of Parts

PLA is frequently thermoformed using forming ovens, molds and trim tools designed for PET or polystyrene (more specifically in the classifications HIPS or OPS). It is critical to note that PP shrinks much more than PLA so that molds and trim tools designed for PP are less optimally used with PLA. Chain rail systems designed to stretch warm sheet to compensate for sagging PP are not necessary or desirable systems for PLA, and may cause PLA sheet to be pulled out of the pin chains. In post trim operations we observe comparable shrinkage between PLA and PET, so PET trim tools adapt well to PLA service. In trim in place operations we observe comparable shrinkage between PLA, PET, and polystyrene. Trim in place molds, matched metal die punches and less optimally heated steel rule die punches (120°C or 250°F) are recommended for trimming PLA thermoformed articles. An ambient temperature steel rule die punch would not be recommended.

For plug assist thermoforming, plugs manufactured from Syntactic foam are typically used. The plug can be coated with a slip coating to prevent sticking in some deep draw applications. Plug shape has had more impact on part quality than has the material of construction. Plug shape is more dependent upon the particular part being molded so no general recommendation can be made regarding PLA.

PLA has a lower softening temperature than PET or PS. Typically oven settings are about 55°C (100°F) or more lower than PS, and about 40°C (75°F) or more lower than PET oven settings. The sheet should be about 90 to 110°C (190-230°F) entering the mold. Aluminum molds are recommended for thermoforming PLA. In addition to being the traditional choice for production thermoforming molds, aluminum is a good metallurgical choice for PLA service (in contrast to carbon steel, which would be more susceptible to corrosion).

PLA has a thermal conductivity that is lower than Polystyrene and PET. The Tg (or deformation temperature) of PLA is also lower than both polymers. In addition, the density of PLA is greater than Polystyrene. All of these factors indicate that the cooling time in the mold will be greater for PLA than either PS or PET. In many thin wall parts, this increase in cooling time is negligible compared to the overall cycle time so that forming rates equivalent to PS and PET have been achieved. However, some thick wall parts will require additional cooling time, which will adversely affect the overall cycle time. The following table summarizes some of the key properties of PLA, PS and PET.

	PLA	PS	PET
Thermal Conductivity (BTU/ft-h-°F) (cal/cm-s-°C)	0.075 0.00029	0.105 0.00043	0.138 0.00057
Heat Capacity (BTU/lb-°F) (cal/g-°C)	0.39 0.39	0.54 0.54	0.44 0.44
Glass Transition Temp (°F) (°C)	131 55	221 105	167 75
Density (lb/ft^3) (kg/m^3)	78 1250	65.5 1050	85.5 1370
Thermal Expansion Coefficient x 10^{-6} ($°F^{-1}$) ($°C^{-1}$)	39 70	39 70	39 70

PLA has a lower extensional viscosity than PET or PS, and is therefore capable of transferring mold detail including tooling marks readily. The natural surface energy of PLA articles is 38 dynes. Corona or flame treatment can be used to ensure high quality printed graphics.

4.0 Regrind Considerations

PLA regrind is not compatible with regrind from any other sheet product. It is necessary to both wipe and water wash clean the grinding equipment and transfer lines or to have dedicated systems for PLA. PLA must be about 40°C (105°F) or less to grind efficiently. Some grinding systems require additional cooling to efficiently grind PLA.

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Safety and Handling Considerations
Material Safety Data (MSD) sheets for PLA polymers are available from NatureWorks LLC. MSD sheets are provided to help customers satisfy their own handling, safety, and disposal needs, and those that may be required by locally applicable health and safety regulations, such as OSHA (U.S.A.), MAK (Germany), or WHMIS (Canada). MSD sheets are updated regularly; therefore, please request and review the most current MSD sheets before handling or using any product.

The following comments apply only to PLA polymers; additives and processing aids used in fabrication and other materials used in finishing steps have their own safe-use profile and must be investigated separately.

Hazards and Handling Precautions
PLA polymers have a very low degree of toxicity and, under normal conditions of use, should pose no unusual problems from incidental ingestion, or eye and skin contact. However, caution is advised when handling, storing, using, or disposing of these resins, and good housekeeping and controlling of dusts are necessary for safe handling of product. Workers should be protected from the possibility of contact with molten resin during fabrication. Handling and fabrication of resins can result in the generation of vapors and dusts that may cause irritation to eyes and the upper respiratory tract. In dusty atmospheres, use an approved dust respirator. Pellets or beads may present a slipping hazard. Good general ventilation of the polymer processing area is recommended. At temperatures exceeding the polymer melt temperature (typically 170ºC), polymer can release fumes, which may contain fragments of the polymer, creating a potential to irritate eyes and mucous membranes. Good general ventilation should be sufficient for most conditions. Local exhaust ventilation is recommended for melt operations. Use safety glasses if there is a potential for exposure to particles which could cause mechanical injury to the eye. If vapor exposure causes eye discomfort, use a full-face respirator. No other precautions other than clean, body-covering clothing should be needed for handling PLA polymers. Use gloves with insulation for thermal protection when exposure to the melt is localized.

Combustibility
PLA polymers will burn. Clear to white smoke is produced when product burns. Toxic fumes are released under conditions of incomplete combustion. Do not permit dust to accumulate. Dust layers can be ignited by spontaneous combustion or other ignition sources. When suspended in air, dust can pose an explosion hazard. Firefighters should wear positive-pressure, self-contained breathing apparatuses and full protective equipment. Water or water fog is the preferred extinguishing medium. Foam, alcohol-resistant foam, carbon dioxide or dry chemicals may also be used. Soak thoroughly with water to cool and prevent re-ignition.

Disposal
DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER. For unused or uncontaminated material, the preferred options include recycling into the process or sending to an industrial composting facility, if available; otherwise, send to an incinerator or other thermal destruction device. For used or contaminated material, the disposal options remain the same, although additional evaluation is required. (For example, in the U.S.A., see 40 CFR, Part 261, "Identification and Listing of Hazardous Waste.") All disposal methods must be in compliance with Federal, State/Provincial, and local laws and regulations.

Environmental Concerns
Generally speaking, lost pellets are not a problem in the environment except under unusual circumstances when they enter the marine environment. They are benign in terms of their physical environmental impact, but if ingested by waterfowl or aquatic life, they may mechanically cause adverse effects. Spills should be minimized, and they should be cleaned up when they happen. Plastics should not be discarded into the ocean or any other body of water.

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