INEOS

Olefins & Polymers USA

Polypropylene Processing Guide

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Introduction

INEOS O&P's polypropylene is a strong, lightweight thermoplastic that offers outstanding toughness, rigidity, and resistance to thermal deformation. Fabricators and designers value these characteristics and have come to consider polypropylene one of the most satisfactory thermoplastic resins for a wide range of applications. This unique material can be steam-sterilized or autoclaved without damage and resists environmental stress-cracking when subjected to most chemical tests.

Several characteristics of polypropylene enable thin section oriented moldings to have virtually unlimited flex life, making it an excellent material for integral hinges in molded parts. These properties include:

- fatigue resistance,
- ultimate tensile strength, and
- ultimate elongation.

Polypropylene is highly responsive to injection speed and pressure and sets up quickly in the mold, enabling molders to attain high production rates. This combination of performance properties gives polypropylene a position in the injection molding field that is unique among thermoplastics. Polypropylene also demonstrates excellent chemical resistance, good abrasion resistance, good dimensional stability, and a high surface gloss on finished pieces.
The versatility of this polymer makes it particularly well suited for film and fibers requiring superior strength, optical qualities, grease resistance, and moisture barrier properties.

Part Design

The design of an injected molded part must ensure functional performance without inducing production problems. The following text discusses some general areas of part design that warrant special attention.

Wall thickness

Typically wall thickness is determined after considering structural strength requirements, aesthetics, and economics (including material and production costs). It is desirable to keep wall thicknesses uniform and to avoid abrupt thickness changes. Otherwise, part weakness and distortion due to corner notch effects and induced shrinkage stresses can result. If transition areas occur, they should be radiused or tapered to minimize stress concentrations and warpage tendencies.

Design reinforcements

To conserve material costs, structural stiffness can be obtained economically by using ribs, edge flanges, and contoured surfaces. Of these, the last two are preferred because they control warpage as well as add form rigidity. In all cases, rib-surface intersections and changes in surface direction must be formed by radii of at least 1/32 of an inch for wall thicknesses up to 0.090 inches. From 0.090 to 0.180 inches, the minimum radius should be 1/16 of an inch.

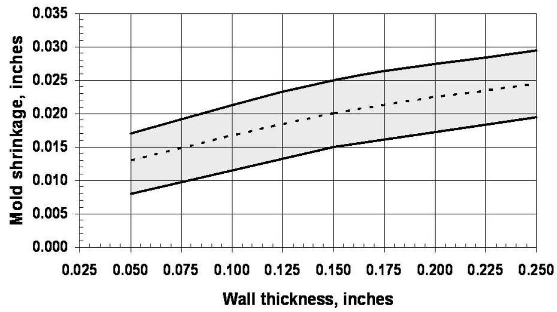
Draft angle

Parts that are formed by plug-cavity type molds must carry draft on all sides to permit ejection. A minimum draft angle of 1 degree per side is needed on smooth-surfaced parts made from unfilled homopolymers and copolymers to prevent seizing due to shrinkage forces. Textured surfaces require added draft to prevent scuffing and to permit easy mold release. Depending on the texture depth, the draft will be from 2 to 5 degrees for unfilled homopolymers and copolymers. Filled resins require more draft, ranging from 4 to 10 degrees. Moreover, their low shrinkage and high stiffness prevent the stripping of all but very minor undercuts.

Shrinkage

The linear mold shrinkage of injection molded parts will vary from 0.008 to 0.025 inches per inch, depending on the particular resin, molding conditions, part design, part wall thickness, and direction of flow. Figure 1 presents the shrinkage of polypropylene versus wall thickness in injection molded parts. These data were obtained from many and varied pieces molded from different grades of polypropylene. Consequently, a range is shown for any wall thickness. For design purposes, the dotted line which represents the average shrinkage is a good starting point.

Figure 1: **Shrinkage of polypropylene**



Sink marks

A high-quality appearance requires minimum surface defects. Sink marks formed by local thick sections due to ribs, bosses, etc., are the most common problems. Sink marks can be virtually eliminated by keeping the rib base no more than 50% of the wall to which it is attached and not higher than 1.5 times the wall thickness.

1) Height: 3W/2
2) Radius of base: W/8
3) Draft: 1.5-2 degrees
4) Thickness: No more than W/2

(W is the thickness of the reinforced wall) The situation with bosses is different since heavy wall thicknesses are necessary for their intended use. In such cases, surface texturing or designing in “mask” is needed to prevent sink marks from being seen. The above problems are minimal with the highly filled resins since their mold shrinkage values are low. They are comparable to ABS and other styrene-based thermoplastics in this respect.

Undercuts

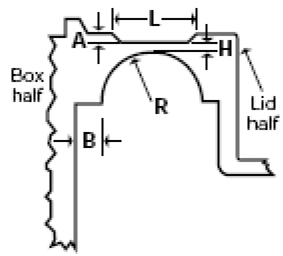
Parts made from polypropylene homopolymers and copolymers can be designed with undercuts that require stripping for release from the mold. Several qualifications must be kept in mind:

- Undercuts must be located so they are not trapped by mold metal, which will cause shearing.
- Undercut designs must use tapered or radiused form to ease the stripping action.
- The extent of the undercut should be not more than 0.035 to 0.040 inches per inch of diameter.
- Filled resins are not adaptable to stripping undercuts.

Integral hinges

A living hinge is the most well-known capability of polypropylene homopolymers and copolymers. Injection molded hinge design features are illustrated in Figure 2.

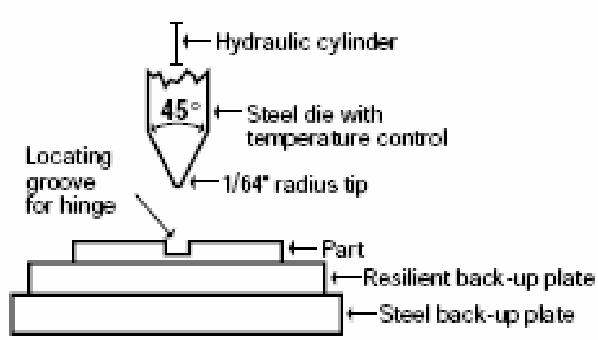
Figure 2: **Injection molded hinge design features**



L - hinge land length – can be 0.06 to 0.90".
H - hinge thickness – ranges from 0.008 to 0.20" depending on ease of closing desired.
A-hinge clearance – about 0.010" is satisfactory to prevent gathering.
B - offset radius – 0.030" minimum. This aids molding the hinge and also promotes alignment between lid and box.
R - hinge radius – to center the minimum hinge thickness and improve moldability.

In molding problems, a heated post forming tool can be used to press hinges. Such hinges can show improved tear strength compared to injection molded hinges. A typical hinge pressing die design is illustrated in Figure 3. Hinges can be formed in both filled and unfilled resins. Unfilled materials, however, yield stronger hinges with a better appearance.

Figure 3: **Typical hinge pressing die design**



Mold Design

All the basic mold, runner, and gating designs have been successfully used with polypropylene from INEOS O&P. To take advantage of a well designed part, the following mold details should be considered.

Sprue

To prevent sprue sticking, highly tapered sides (3 to 5 degrees including angle) are required. It is also desirable to keep the sprue length down to 3 inches to help minimize ejection problems. Extended nozzles are used if the sprue length becomes objectionable. Various types of sprue pullers have been successfully used such as the hook, reverse taper, or groove. The latter two are preferred.

Runner shapes and layout

All of the basic runner shapes (full round, half round and trapezoidal) are usable. The important factors are:

- Minimum runner diameter (or equivalent cross-sectional area) leading into a gate should be 0.250 inches. This runner should never have a diameter less than the heaviest wall section in the part. Primary runners leading from the sprue to the sub runners should decrease in size at branch points.
- Balanced runner systems are desirable to promote simultaneous filling of multi-cavity molds. This technique can lead to extensive runner scrap generations. Other less balanced runner systems can be used for the sake of economy. In such cases, balancing can be assisted by stepping down the runners in the direction of flow and by adjusting gate sizes.

Gate types

All basic gate designs have been used with success in molds designed for polypropylene. The only basic restrictions are as follow:

- Gate diameter (or equivalent cross-sectional area) should be no less than 50% of maximum wall thickness. Minimum gate diameter should be 0.030 inches.
- Gate land length should be no more than 0.040 inches to minimize pressure loss of the flowing molten polymer.
- All sprue gate entry points should be reinforced with “dimples.” This assists melt flow distribution and absorbs packing stresses, reducing the tendency for brittleness.

Gate location

Generally, gates should be located so that the melt flow is from thick to thin sections. The other major consideration is to create as balanced a cavity filling pattern as possible for optimum control of differential shrinkage (warpage). An example of this problem is center gating of a rectangular part, which causes upward warping in opposite corners and downward warping in alternate corners. To minimize this, gates should provide as much flow in one direction as possible. Edge gating down one half to two-thirds of the short side or multiple gating in a row along one edge or along the center line is also effective.

Integral hinge gates

Hinge gating requires a consistent, uninterrupted flow across the hinge web to prevent laminar flow and hinge failure. Cup, container, and closure gates should be recessed to reduce gate scars, long gates, and the possibility of impact directly on the gate. Filled materials require special consideration in gate location. Weld line formations can be weak if they fall in areas that will bear stress or impact. This is particularly true if the wall thickness in the weld is thin – i.e., less than 0.080 inches. Gates should be designed larger than normal and located to minimize weld line formation.

Mold temperature control

Water channels must be located in both halves of the mold. Where straight-through, cross-bored holes are applicable, their diameters should be 0.5 inches and spaced on 1.5 to 2 inch centers. Long cores should be controlled by bubblers. Even thin core projections can be cooled by bubblers. In some cases, however, highly conductive metal inserts are force-fitted into such projections. Water can be directed at the base of the inserts to draw off mold heat. Mold shrinkage and control of warpage dictate the use of mold temperature control. A separate mold temperature control channel parallel to the hinge section is recommended in integral hinge molds. This line often is run hot (160-

180°F) to assist melt flow across the restricted area.

Clamp requirements
The normal clamp estimating factor is two tons per square inch of projected mold cavity area. However, integrally hinged parts have been found to call for at least 4-6 tons per square inch of projected area. It is preferable to have a safety factor for this requirement to eliminate production quality problems.

Knock-outs
Balanced knock-out forces are helpful in controlling part quality. Large knock-out pins and knock-out rings are recommended. Undercuts which require stripping should have individual knock-outs to prevent unbalanced ejection. A minimum knock-out pin diameter of 0.250 inches is suggested. Air relief (or poppet valves) have been shown to be helpful when ejecting off long cores. Also, long cores should not be polished, but vapor honed to minimize vacuum traps further.

Vents
Vents should be located at the farthest extremities of the part and at points where air can become entrapped. Vents are usually 1 mil deep for the first 0.005 or 0.010 inch, flaring to 5 mils at the extremity of the mold. Knock-out pins slightly flattened on one side can also serve as vents. In addition, poppet valves can be used. In extreme cases, evacuating the mold may be necessary.

Material Selection
Resin flow
The ability of polypropylene resins to fill molds relates to their molecular weight properties and generally is referred to as melt flow. Melt flow data, as determined using ASTM Procedure D1238, are used by the thermoplastics industry to describe resin flow. Because the test is performed at a very low shear rate, results can be misleading when comparing polymers with significantly different molecular weight distributions. Polymers with broad molecular weight distributions have greater flow at injection molding shear rates per unit of melt flow than do polymers with narrow distributions. Melt flow data, however, can be used to describe polymer flow except in extreme cases. Polymer flow should be a primary consideration when selecting a grade of resin for a particular application. Each molding setup will require a specific flow range for optimum molding and molded part properties. Resins with improper flow can be "forced" to run in setups. Doing so, however, reduces the size of the molding window and can compromise productivity and quality of the parts. Figures 4 through 9 show typical molding area diagrams in three melt flow rate ranges (low, medium, high) and the effects of nucleation and antistat on flow.

Figure 4: **Molding area diagram for 5 MFR general purpose**

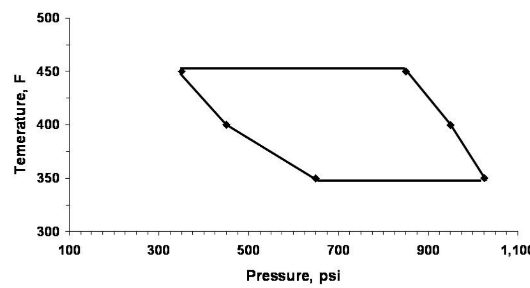


Figure 5: **Molding area diagram for 5 MFR nucleated antistat**

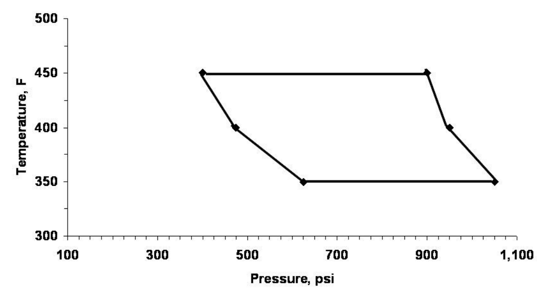


Figure 6: **Molding area diagram for 12 MFR general purpose**

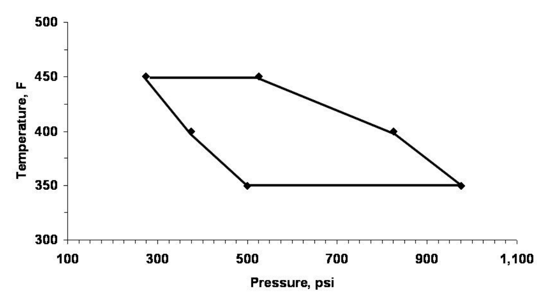


Figure 7: **Molding area diagram for 12 MFR nucleated antistat**

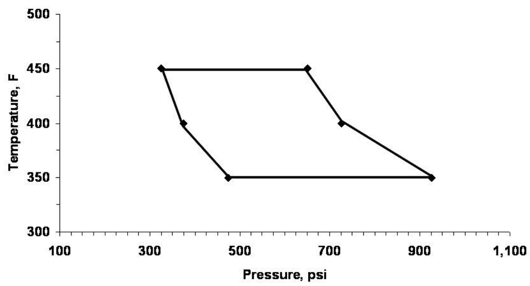


Figure 8: **Molding area diagram for 35 MFR general purpose**

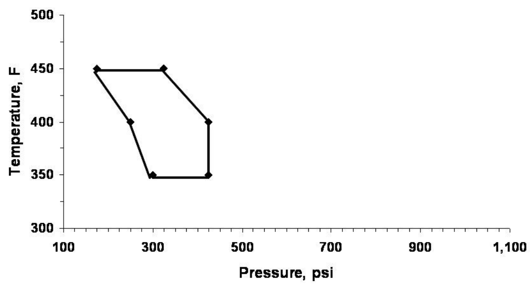
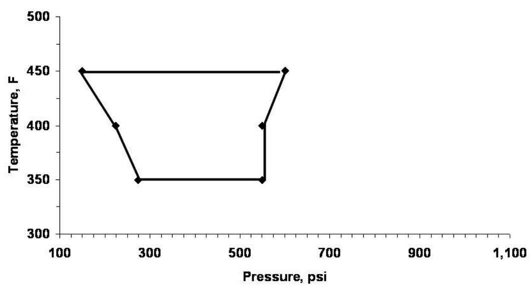


Figure 9: **Molding area diagram for 35 MFR nucleated antistat**



When selecting a flow for a molding setup, we recommend one with which parts can be molded at melt temperatures between 400 and 450°F at injection pressures between 1000 and 1500 psi. We also recommend selecting the lowest flow resin that will run under the above limits. Lower flow resins will have higher molecular weights and should produce molded parts with better toughness properties. Common problems resulting from use of resins with flows that are too high for a setup include:

- flash,
- difficulties in packing out parts,
- bubbles in the parts, and
- brittleness in molded parts.

When using resins that are too low in flow, possible problems include:

- short shots,
- packing causing seizing or sticking, and
- high melt temperature requirements causing longer cycle times or degradation.

Antistat

Because of its excellent electrical insulating properties, polypropylene has a tendency to retain static charges caused by processing and handling. This condition attracts dirt to the polymer surface. To eliminate this problem, antistatic agents can be added to the resin before processing. The antistat additive "blooms" to the surface, dissipating electrical charges. The antistat has several other interesting features. It acts as a slip agent in closure applications, allowing a tighter fit while using the same torque. This helps prevent leaking of the product during storage and shipping. It also acts as a processing aid for nucleated polypropylene (which increases its molding window) and as an internal mold release agent for all polypropylene grades. The major drawbacks of adding an antistat are the inability to print (cannot be surface-treated) and the white film (bloom), which shows on the surface of dark colors after several months of storage.

Nucleation

Polypropylene forms crystallites during cooling in the mold. General purpose grades form a small number of large crystals with a relatively large non-crystalline space between them. The addition of nucleating agents "seeds" the melt with growth sites. This results in the formation of a large number of small, closely packed crystals, thus giving:

- excellent thin section clarity,
- increased physical properties [flexural modulus, heat deflection temperature, stain resistance, and barrier (water vapor + O_2) properties], and
- faster mold setup time (reduced cycle time).

The disadvantages are:

- shrinking on the core,
- sticking if parts are not ejected fast enough, and
- reduced knit line strength.

Phthalocyanine pigments (blue and green) are strong nucleating agents and will nucleate general purpose grades of polypropylene.

Injection Molding

Polypropylene can be molded in standard screw molding equipment without alterations. Although pre-drying is not necessary under normal conditions, it may be required for filled resins. Cylinder temperature and injection pressure are the two most important variables available to the molder. These two closely related variables are discussed in the following text along with other molding parameters.

Cylinder temperature

Best results are obtained when polypropylene is molded at cylinder temperatures ranging from 400- 570°F. Cylinder temperatures should be 25-50°F higher than the minimum temperature required to fill the part, but not over 570°F. In most cases, molding temperatures will be in the 400-525°F range. A cylinder temperature profile is recommended with the hopper or feed section being 30-50°F lower than the nozzle. When greater mixing is required, a bell-shaped temperature profile may be used where feed and front temperatures are lower than the center zone. Improper cylinder temperatures can cause a variety of problems. Too high of a temperature can cause problems with flashing and burning and with shrink phenomena such as sinking, warpage, shrinkage, and void formation. There is usually an optimum temperature above or below which shrinkage or warpage increase. Brittle parts also can be caused by either too high or too low of a temperature. Too low of a temperature can promote flow marks, weld lines, poor surfaces, lamination, and short shots.

Injection pressure

The proper injection pressure depends largely on part size and configuration. Pressures usually range from 1,000 to 1,500 psi. Best results are obtained at higher pressures, up to about 75% of the press capacity. Pressures should be high enough to fill the part and to avoid problems with shrinkage, voids, sinks, and pigment dispersion. Too much pressure can cause parts to flash, burn, and stick in the mold.

Injection time

Injection time should take up a good portion of the overall cycle. Injection time plays a relatively minor role in controlling warpage as compared to its major role in the control of shrinkage.

Mold temperature

Mold temperatures usually range from 60-150°F. Temperatures should be high enough to produce good part surfaces and to avoid flow marks, weld lines, lamination, brittle parts, voids, short shots, and core sticking. Temperatures should not be so high however, that shrinkage, warpage, sinking, and cavity sticking become problems. Cooling the mold should be uniform unless differential cooling is needed to reduce part warpage.

Cure time

Allow sufficient cure time to cool the part before removing it from the mold, preferably to about 130°F. Shortening the cure time increases warpage. Sinking and shrinkage also increase if the cure time is shortened.

Back Pressure

We recommend using minimal back pressure, in the range of 50-100 psi (gauge). Higher back pressures usually are not needed and can have an adverse effect on screw recovery. Higher back pressures may be used, however, if more screw shear for melting or pigment mixing is needed.

Screw speed

Long screw recovery times can limit productivity. Increasing screw speed and/or reducing back pressure are obvious adjustments that can correct this problem. Increases in melt temperature, particularly in the rear zones, will also shorten screw recovery times. The major polymer variable affecting screw recovery is external additives that interfere with polymer pick-up in the feed zone. Pellet size and geometry can affect screw recovery, but to a lesser degree.

Mold release

Mold release agents should not be necessary due to the excellent release characteristics of polypropylene. Sticking problems that cannot be resolved by molding conditions can generally be corrected by mold changes. These changes are less expensive than the loss of decorating ability and cycle time and the high mold maintenance associated with mold release applications.

Extrusion

General

Polypropylene, along with any pigment or stabilizers the customer might add, is passed through an extruder having at least four barrel temperature control zones, a screen pack, breaker plate, adaptor, and die. Good temperature control in each of these areas is required. For general extrusion, the temperature range from feed throat to front is 390- 450 °F, with the adaptor and die at the same temperature as the front barrel zone. Cast film, fibers, and yarns require higher temperatures; the rear at 430-490°F and the front, adaptor, and die at 490°F. These temperatures should be considered only as guidelines and will vary with individual processes. Reverse profiles have been used where more mixing is required for pigment dispersion or melt uniformity.

Downstream

Sheet – In solid sheet extrusion, the polymer [0.5 to 6 melt flow rate (MFR)] is melted and mixed in an extruder, then pushed through a wide die having a relatively narrow opening. The die opening is matched to the desired sheet thickness. Then the molten polymer is pulled from the die over cooling rolls and conveyed to a take-up station. Here it is either cut into lengths or wound on a roll, depending upon the gauge and its end use. If needed, the sheet can be cooled additionally with air blowers as it is conveyed to the take-up station. Film – Film is generally made by one of three extrusion processes. The film types (and processes) are cast (6 MFR), blown (8 MFR), and biaxially oriented OPP (2-3 MFR). In the cast film process, the flat extruded film may be quenched using chill rolls or a water bath. In the blown film process, air or water quench may be used. Blown film tends to have a better balance of physical properties since some biaxial orientation is imparted during blowing. The majority of polypropylene that INEOS O&P sells for film applications is used in the manufacture of biaxially oriented film (OPP). It is made by a tubular process (bubble process) or a cast-tenter frame process. The majority of the world production of OPP is made by the tenter frame process. In the bubble process, a relatively small diameter tube is formed, quenched, collapsed, reheated, and blown. During the blowing step, the film is stretched circumferentially and in the machine direction. The tubular product may be slit to form flat film or may be made directly into items such as seamless bags. In the tenter frame process, an extruded sheet is stretched in the machine direction using a series of orienting rolls. Then it is stretched in the transverse direction in the tenter frame unit. Film lines based on the tenter frame process tend to be very large and complex. A film line from extruder through winder may be more than 300 feet long and produce film 200 inches or more wide at rates greater than 500 feet per minute. Tape yarns – Polypropylene with melt flow rates between 2 and 6 is commonly used in the extrusion of tape yarns. Polypropylene is extruded from a slot-type die 1-3 meters wide with die gap adjustment for the desired film thickness. The film is quenched by one of two methods. The most common method is a water bath quench in which the film enters a tank filled with water at about 95°F. Dwell time in the tank is 2-6 seconds, and film speeds range from 20-45 meters per minute. Similar speeds are achieved in chill roll quenching where the molten film is forced into contact with a smooth chilled roll using an air knife. One or two chilled rolls are commonly used. After quenching, the film is slit into tapes by a row of equally spaced blades. After slitting, the tapes are often de-lustered by passing them over then under a set of rolls surfaced with fine grit sandpaper. The surface speed of these rolls is greater than the speed of the tapes. The resulting abrasion both reduces the gloss of the tape surface (undesirable in some products such as primary carpet backing) and increases yarn-to-yarn friction coefficients. This allows winding of acceptable packages (a reduced tendency for the wound package to deform during handling). The de-lustered tapes are then heated and drawn out at ratios of 5:1 to 18:1, depending upon the tensile properties required in the product. Yarns for carpet backing would fall into the low end and cordage into the high end of this draw ratio range. After drawing, some products (grass carpet yarns and cordage) are fibrillated. Fibrillation is the process of forming multiple short cuts or splits in the yarn parallel to the yarn axis. This is accomplished by passing the drawn tape over a roller that has precisely placed rows of sharpened pins. Each pin is 2-4 mm in length. The surface speed of the fibrillator roll is greater than the yarn speed, causing the pin to first penetrate the tape, then "slice" the tape for a given length (determined by the difference in surface speeds). The result is a "fishnet" type pattern in the fibrillated tape. Fibrillated tapes can be twisted more uniformly and provide better "hand" or feel in carpet face yarns. After drawing (or fibrillation), the tapes are reheated, and drawing stresses are allowed to relax from 2 to 10%. The tensile properties and latent thermal shrinkage needed in the end product determine the amount of relaxation. After relaxation, the finished tape yarns are wound onto packages. Final weights range from 5 to 50 pounds. Tape extrusion lines operate at rates from 200 to 2000 pounds per hour and require from 1 to 3 operators.

Fiber

Polypropylene staple fiber end uses include carpet face yarn, diaper coverstock, apparel and upholstery yarns, and geotextile nonwovens. Worldwide usage of the fiber is growing rapidly, as is the range of its end uses. The process for manufacturing fibers can be summarized in the following steps:

- melting in extruder,
- extrusion through spinneret holes,
- quenching the filaments,
- spin finish application,
- drawing the filaments,
- crimping the filaments,
- cutting the filaments into staple fiber, and
- baling the fiber.

Manufacturing equipment can be divided into two groups by the type of quenching scheme employed. Conventional melt spinning is based on nylon spinning and was used exclusively for several years. The conventional systems use a cross flow of chilled air over the first 2 meters of travel from the spinneret, which contains 200-1000 holes. Spinning speeds range from 800 to 4000 meters per minute. Filament tows from 8-16 spinnerets are drawn from a creel and run on the draw line. The filaments are heated and stretched there; then crimped, cut, and baled. On compact or short-spin systems, filaments are cooled by a blast of air within a few millimeters of the spinneret. These spinnerets contain 5,000-75,000 holes, and spinning speeds of 20-140 meters per minute are common. Filament bundles from 2-16 spinnerets are combined and move directly to the fiber line in this one-step process. The capital investment required for installation of compact spinning equipment is much less than for conventional equipment. It is expected that almost all future expansions in polypropylene staple fiber will utilize compact equipment.

Thermoforming/Solid Phase Forming

An intensive development effort by machinery suppliers has resulted in new mechanical forming equipment. The use of this equipment is expected to accelerate polypropylene's use in packaging applications. The amount of polypropylene used in the fabrication of thin-walled food containers could grow dramatically over the next three to five years. Properties conducive to polypropylene's selection for packaging applications are:

- resistance to chemical attack and high temperature
- good impact/rigidity balance
- low density
- good barrier properties, and
- non-toxic characteristics.

Hot-fill and microwave oven containers, for example, are fabricated with polypropylene because of its superior heat resistance. The resin's long term favorable supply and competitive pricing will be added inducements to growth. The primary deterrent to widespread use of polypropylene for thermoforming is its higher and narrower forming temperature range. The temperature at which sheet begins to bubble is only 15-20°F above the transition temperature at which it becomes formable. Successful forming, however, can be realized with a minimum of sagging if the sheet is heated above the 300°F softening point, but below the 333°F melt point. Within this range, polypropylene orients, resulting in improved clarity, strength, and barrier qualities. Above the melt point, the resin does not orient and its low melt strength at that temperature leads to sagging, which makes thermoforming difficult. Below the softening point, the resin's stiffness has a similar adverse effect. Temperature control is a critical processing condition for forming polypropylene, and maintaining the desirable range is difficult because of the resin's relatively poor heat conductivity. Consequently, preheating is required to prepare the sheet stock for forming. The temperature during forming must also be controlled. If it is not, thick and thin sections will result that cannot be molded with accuracy. Finally, at the end of the cycle, heat must be extracted before the part can be removed. Ideally, temperature cycling should be as fast as possible in order to attain a high production rate. Molds for polypropylene are generally made of aluminum, which has high thermal conductivity. Channels are used for carrying liquid coolant to hasten temperature cycling. Although molds are important to proper thermoforming, equipment innovations have been the principal stimulus in the renewed interest in forming polypropylene. Machines currently available illustrate the two techniques developed. Stretch forming is used for cylindrical and rectangular containers. Where thin-walled items and heavy, hollow shapes are required, pressure forming techniques are employed. Processing at a temperature just below the softening point is a common requirement. In pressure forming, a multi-stage oven heats the sheet, which is clamped over the molds. A heated plug forces the material into the mold cavity, followed by a blast of cold air that forces the hot sheet against the cooled mold surface. Then the part is released. Other machine developments involve alternate approaches to handling the sheet during processing. A shuttle-mold system, where the female elements shuttle back and forth across the web after forming and trimming the part is popular for molding cups. Trimmed parts cool in the mold cavity before ejection. Rotary systems are also employed. Instead of carrying sheet through the system in a straight line, preheating, forming, and trimming stations are arranged in a circle. Earlier and more complete control and elimination of sagging problems in the forming stage are readily attainable.

Finishing

Hot stamp printing

In the hot stamp printing process, a pigment is transferred from a dry carrier strip (cellulose acetate. Mylar®, cellophane, or glassine) to the substrate using a combination of heat, pressure and dwell time. Hot stamping can be used to cover small areas as well as large surfaces such as cabinets. Generally, the range for hot stamping polypropylene is 240-350°F. The stamping foil is formulated for use on specific substrates and/or specific applications. It can be obtained in any color, including metallic. Alterations in gloss are also possible. To ensure that the proper foil is obtained, the foil supplier should be made aware of the substrate type and any specific requirements related to the application. If sample plastic parts are available, the foil supplier should work with them to aid in providing the correct foil. Substrate surface treatment prior to hot stamping is not necessary to obtain adhesion. If mold release is used, it should be a paintable variety. Hot stamping should not be done on parts covered with mold release agents containing silicone or on grades containing an antistat.

Vacuum metalizing

Vacuum metalizing is the process of depositing a thin layer of aluminum on a suitable substrate. This is accomplished by vaporizing the aluminum and condensing it on the parts while under high vacuum. The steps necessary to achieve satisfactory results are:

- primer coat (polypropylene only),
- base coat,
- heat cure (volatiles solvent removal),
- vacuum metalize,
- top coat,
- heat, and
- color dye (optional).

The organic coating system is a critical aspect of metalizing on polypropylene. The first coat provides the necessary adhesion between the plastic substrate and the vacuum deposited metal. The top coat, which protects the metal, must have good adhesion and resist chemical attack, humidity, and abrasion. As with other forms of decorating, mold release and antistat grades should not be used.

Surface treatment

Polypropylene molded parts, sheet, or film are normally impervious to solvent attack and require surface preparation prior to decorating. Several methods of surface treatment are available for improving the adhesion of printing inks, silk screening inks, and paint to the parts.

Gas flame
This is the most popular method and provides a chemical bond on the polypropylene surface for the adhesion of inks and paint. Parts are rapidly passed through an oxidizing gas/air flame at the corona or at the point where the dark blue and light blue of the flame meet. This forms carbonyl groups on the surface for adhesion and reduces surface tension to allow wetting. The exposed carbonyl functionality begins to oxidize within a short period of time; therefore, printing or painting cannot be postponed. Flame contact time is of extreme importance. If contact time is too short, the chemical reaction does not take place. If too long, surface melting of the polypropylene occurs, making the part useless.

Corona discharge (electrical discharge)
Corona discharge is similar to the flame treatment in that surface carbonyl groups are formed. The source of the corona is a DC electrical treater bar that provides high amperage cool discharge directly on the surface of the film or sheet. This method is used when flame treatment is not possible due to the heating involved. Mechanical etching, sanding, wire brush, or grit blasting can be used for mechanical bonding of paints and is effective if a fine uniform surface roughness can be produced. This method, however, is not as effective as other forms of surface treatment.

Machining Properties
The machine ability of polypropylene is excellent. It may be processed on any standard machine shop equipment. Sometimes a coolant is required.

Turning
This may be done on any conventional metalworking lathe. Tool bits should be ground similar to those for cutting hard wood. As in the machining of other plastics, the best surface finish is obtained with a high speed, fine feed, and sharp cutting tool.

Chasing
Excellent threads can be cut into polypropylene in either fine or coarse series with good results.

Sawing
Polypropylene can be sawed effectively using table saws, jigsaws, and band saws with some modification. Unless sufficient tooth clearance is provided, too much friction will melt the thermoplastic. We suggest 8 teeth per inch.

Drilling and tapping
Standard twist drills are suitable for use with this plastic as are standard machine taps. High drill speeds and tool travel should be used when drilling.

Milling and shaping
Polypropylene can be milled or shaped readily on standard machine shop tools. A good finish can be produced in either operation. Burr formations are not a problem since they can be removed easily.

Joining and Welding Methods
Spin welding
Limitation: Circular joint design required. Spin welding is a frictional heat method of joining parts with circular joint configurations. One part is held stationary and the other part is rotated in contact with it. The heat of friction reaches the polymer's melt temperature rapidly (within 2 seconds). The spinning motion is stopped and the parts fuse together. Sufficient time is allowed for the weld to cool under pressure before removing from the mandrel. A lathe, drill press, or specially designed equipment can be used.

Prime factors influencing weld strength are:

- velocity of the spinning part,
- pressure during welding,
- contact time producing the frictional heat,
- joint configuration, and
- cooling time.

Generally, the joint interface should incorporate a 0.012-inch interference, flash traps (which provide additional weld lines), and a locating groove for alignment.

Hot gas welding
Limitation: Not suited to high volume operations. A hot gas gun is used through which either air or nitrogen flows. Nitrogen normally is used to minimize oxidative degradation of the polymer. The welding rod should be of the same material as the parts

being joined. The mating edges of the parts should be beveled prior to welding. The tip of the gun should be oscillated close enough to the bond area so that the welding rod and beveled edges become soft. The welding rod is forced under moderate pressure at a 90 degree angle into the weld bed. Round or triangular rods may be used. Best results are usually obtained with triangular rods.
Factors affecting weld strengths are:

- joint design,
- pressure on the welding rod,
- temperature at the weld bed and of the rod,
- welding experience of the operator, and
- the number of weld passes.

Hot plate welding or butt welding

Limitation: Generation of flash.
This method is used extensively in joining pipe. A hot plate or heating mirror with a Teflon® coating is used. The plastic parts are brought into contact with the hot plate, and their surfaces softened. The parts are then joined together under moderate pressure and allowed to cool. Excessive pressure can cause the softened material to be pushed aside and a poor bond will result. Too much pressure and/or too much heat can also cause high ridges to form and impede flow through the pipe.

Heated tool welding

Limitation: Generation of flash.
Fabrication of tank liners from sheet stock is one application for this type of welding. This method is like hot plate welding except that tools similar to soldering irons are used. The tool is heated sufficiently to soften the plastic sheet to form beads on both sides of the weld line while the tool has contact with the plastic. The softened surfaces are then joined together under pressure.

Thermal impulse sealing

Limitation: For film only.
In this method, a timed electrical impulse is passed through a heating element (usually made of Nichrome wire) causing the wire to heat immediately. The wire is under a Teflon® coating that acts as a release liner. The film is held in place by a rubber bar that provides the welding pressure. Since the heat must travel through one layer of film to the interface, film thickness determines the sealing conditions of temperature, dwell time, and pressure. Seals can be made through contaminants such as liquids, pastes, etc.

Ultrasonic welding

Limitation: Vibration transmissions are dependent on the plastic's modulus.
Ultrasonics use the mechanical vibration of sound waves at a frequency of 20,000 cycles per second. A transducer converts electrical energy to mechanical energy in the form of vibrations. This action creates heat at the weld interface and results in a bond. In remote sealing, the vibrations must travel greater distances. The modulus of the plastic is the prime factor in determining if it can be joined. The higher the modulus, the more easily the polymer can be joined. Polystyrene is easier to weld than polypropylene, which in turn is easier to weld than high density polyethylene.

Effects of radiation

Ultraviolet (UV)

Polypropylene is greatly affected by UV radiation. Exposure to strong, direct sunlight for six months will cause severe loss of strength properties unless a UV inhibitor or high loading of carbon black pigment is used. Even with high inhibitor or pigment addition, service life expectancy under severe sunlight conditions is limited.

Microwave

Polypropylene is transparent to microwave energy and is used extensively for microwave oven parts and microwaveable food containers.

Gamma

Polypropylene is attacked by gamma radiation sterilization dosage unless it is stabilized against it.

Internal Recycle

Regrind

Polypropylene regrind from spruces, runners, and rejected parts may be safely re-blended with virgin resin at 30-40% levels on a constant add-back basis. Higher percentage levels can cause an unacceptable drop in impact and flow properties. This is due to molecular weight reduction caused by too great a percentage of material having three or more heat histories.

Coloring

Colored plastic products are realized through three primary approaches:

- pre-colored resins,
- tumble blending of natural resin with dry pigments or color concentrates followed by introduction to the molding equipment, and
- automated proportioning and blending of pigments or color concentrates with natural resin arranged to provide a continuous feed to the molding machine.

Advantages such as improved operational flexibility and favorable economics have promoted the adoption of captive coloring techniques.

Dry color

A blend of pigments formulated to provide a color match is prepared by a pigment supplier. Dispersing aids are included. The pigments are selected for blending with a specific amount of natural resin to provide the desired color. Dry color is preferred for processing operations involving limited quantities of resin and/or a broad variety of colors.

Advantages:
- low cost compared to pre-colored resin and color concentrates, and
- bulk quantities of natural resin can serve as the base for a variety of colors.

Disadvantages:
- processor is responsible for color realized (processing equipment must provide adequate melt mixing to disperse pigments uniformly), and
- blending operation is required to distribute the pigment in the natural resin,
- contamination of the equipment and area is likely, and
- difficult to remove residual pigments from blending equipment, feed hoppers, etc.

Solid color concentrates

Solid color concentrates are high loadings of pigment pre-dispersed in resin binders. Concentrates are formulated to provide a specified color match when blended with a predetermined amount of natural resin. The proportion of each is expressed in a letdown ratio – i.e., 10:1, 20:1, etc. The resin is indicated by the first number; the concentrate by the second.

Advantages:
- lower cost than pre-colored resins,
- bulk quantities of natural resin can be used, and
- efficient color changes in the processing operation.

Disadvantages:
- processor is responsible for color, and
- blending operation is required to distribute concentrate in the natural resin.

Addition of concentrate and blending can be implemented through use of special automatic equipment designed for this purpose.

Liquid color

Liquid color concentrates are a high loading of pigment dispersed in liquid media. Let-down ratios of 100:1 to 200:1 are typical. Generally, the concentrate is metered directly into the throat of the hopper on the processing equipment.

Advantages:
- efficient, low-cost method for coloring plastic materials,
- eliminates prior blending of natural resin and concentrate, and
- liquid carrier improves dispersion of coloring media in resin matrix.

Disadvantages:
- difficult to remove residual pigments from equipment, and
- processor is responsible for color realized.

Injection Molding Troubleshooting Guide

Problem	Cause	Remedy
Short shot	Molding	Increase shot size Increase injection time Increase injection pressure Increase cylinder temperature
	Mold	Open gates, runners, sprues Adjust gates, vents, runners Use higher flow resin Redesign parts
Flash	Insufficient clamp pressure	Increase clamp pressure Use larger press
	Molding	Reduce injection time Reduce cylinder temperatures Reduce injection pressure
	Foreign material on mold face	Clean mold faces
Sticking in cavities	Severe packing	Decrease pack pressure and/or pack time Increase cylinder temperature and decrease fill pressure
	Insufficient cooling	Increase cycle time
	Mold design, condition	Polish cavity surface Remove undercuts Remove undercuts Increase draft on draw areas Modify geometry on core to increase friction Relocate gates
Sticking on cores	Severe packing	See sticking in cavities
	Cycle too long	Reduce cycle time
	Mold design, condition	Polish cores Remove undercuts Increase draft Improve knock-out system
Warp	Insufficient cooling	Increase cycle time
	Stresses due to mold design	Relocate gates: end gating preferred Redesign parts to minimize variations in wall thickness
	Differential mold temperatures	Take care to eliminate hot spots in the mold Temperatures on the A and B mold halves must be similar
	Molded-in stresses	Mold at high temperatures, low pressures, and moderate fill rates

Problem	Cause	Remedy
Sink	Insufficient packing	Increase pack pressure and/or pack time Reduce cylinder temperature and increase fill pressure Reduce fill rate
	Mold design	Open gates Gate into heavy sections Reduce wall thickness of ribs and bosses
Dimensional flaw	Parts too small	Increase pack pressure and/or pack time Increase cylinder temperatures Increase gate size Change resin Rework tool
	Parts too large	Decrease packing pressure and/or pack time Decrease cylinder temperature Change resin Rework tool
Splay	Wet material	Dry resin
	Mold sweating	Run mold temperature above the dew point
	Disorderly flow front	Slow down fill rate Reduce cylinder temperatures
	Insufficient packing	Increase pack pressure and/or pack time
Flow marks	Molding	Increase cylinder temperature Use moderate fill rates Increase mold temperature
	Mold	Move gate so that flow front impinges on some mold feature Move gate to put flow marks in a less critical area Polish cavity and core surfaces
Brittle Parts	Polymer degradation	Reduce cylinder temperatures and/or residence time Change polymer
	Molded-in stresses	Raise cylinder temperatures Use moderate fill rate Reduce packing pressures and/or pack time Change polymer
	Contamination	Check color concentrate for pigment, pigment dispersion, and base resin type Check polymer
	Part design	Avoid sharp corners Avoid knit or weld lines in critical strength areas

Problem	Cause	Remedy
Poor gloss	Molding	Increase fill rate Increase mold temperature Increase packing
	Mold	Polish mold
Gas burning	Molding	Reduce fill rates Reduce cylinder temperature
	Mold	Check venting and rework if necessary Clean vents
Poor knit lines	Highly nucleated polypropylene	Change resin or resin with a dispersed phase, etc.
	Part design	Change gating to place knit line in less critical area Use overflow tabs to induce polymer mixing at knit line Use ribs, thickness, increased flow length after knit, etc.
	Molding	Increase cylinder temperatures Use slow fill rates Increase mold temperatures
Poor color dispersion	Color concentrate	Change concentrate Increase cylinder temperatures and lengthen residence time
	Dry color	Be sure that a good pre-mix is achieved Switch to appropriate color concentrate Use dispersion plate or mixing nozzle
Drool	Molding	Reduce cylinder, runner, temperatures, etc. Lengthen cycle time Use screw suck-back
	Press	Use shutoff nozzle
	Mold	Use valve gating

Regulatory Information

The product and uses described herein may require global product registrations and notifications for chemical inventory listings, or for use in food contact or medical devices. For further information, please visit our web site at www.ineos-op.com.

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