K-RESIN®
STYRENE-BUTADIENE COPOLYMERS
The Smart Choice™

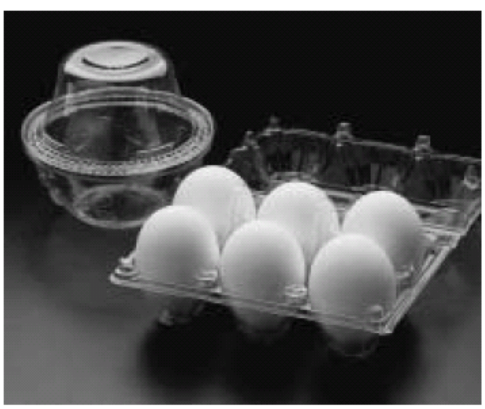
TIB 201
Sheet Extrusion and Thermoforming

Introduction

K-Resin® styrene-butadiene copolymers (SBC) are a family of clear resins produced by Chevron Phillips Chemical Company LP. K-Resin® SBC were commercialized in the early 1970s. Since that time, they have grown steadily in the marketplace as more and more applications have been developed utilizing these polymers' unique blend of sparkling clarity and impact strength.

Applications range across the spectra of conventional processing techniques. K-Resin® SBC, alone or in blends with crystal polystyrene, can be extruded into sheet and thermoformed on conventional equipment at high output rates. The favorable economics of K-Resin® SBC, along with high productivity, have made possible tough clear disposable drinking cups, lids, and other packaging applications. These materials process equally well in injection molding, providing good cycle times and design flexibility. An example of an injection molded application is the clear living hinge box. The part is filled through the narrow hinge, yet still has enough toughness to provide good hinge life. In blow molding, K-Resin® SBC will process on most conventional equipment, allowing the molder to run a crystal clear bottle without expensive machine modifications, special molds, different screws, or dryers. K-Resin® SBC are blow molded in a broad range of sizes and shapes, from small pill bottles and medical drainage units, to very tall display bottles. They can also be injection blow molded into extremely high impact bottles with glass-like clarity. Produced as a film, K-Resin® SBC makes a clear, stiff, high gloss film suitable for applications such as candy twist wrap, shrink sleeves and overwrap. If extreme processing and regrinding conditions are avoided, the polymers can be reprocessed in multiple passes with minimal change in properties and processing.

A feature that makes K-Resin® SBC more economically attractive than other clear plastics is their low densities. K-Resin® SBC have a 20–30% yield advantage over non-styrenic clear resins.



All K-Resin® SBC grades as shipped by Chevron Phillips Chemical, meet the specifications of the United States FDA Food Packaging Regulation 21 CFR 177.1640 or the specifications of an effective United States FDA Food Contact Notification. By virtue of this FDA compliance, K-Resin® SBC grades may be used as a component of articles for use in contact with food. Most K-Resin® SBC grades meet the food contact requirements for EEC Directive 2002/72/EEC and all its amendments.

Most K-Resin® SBC grades have been tested and meet USP Class VI requirements and can be sterilized by ethylene oxide gas, electron beam, or gamma radiation. More detailed information on the bio-compatibility of K-Resin® SBC can also be obtained in TSM 292 "Medical Applications of K-Resin® SBC".

K-Resin SBC Grades

Several K-Resin® SBC grades (KR05, KK38, XK40, XK41 and XK44) have been developed for the sheet extrusion and thermoforming processes. These grades are typically blended with crystal polystyrene for use in Single Service and Rigid Packaging Markets.

KR05, KK38, XK40 and XK41 were developed for the Single Service Markets (cups, lids, deli items). KR05 blends with crystal polystyrene have exceptional clarity and good toughness. KK38 and XK40 blends with crystal polystyrene have improved toughness and slightly higher haze properties (using lower SBC content in the blend, which improves economics) compared to the KR05 blends. XK41 blends with crystal polystyrene provide a middle ground for both optical and toughness properties when compared to the KR05, KK38 and XK40 blends mentioned above.

XK44 was developed specifically for Rigid Packaging Markets (medical trays, clam shells, secure packaging, etc). XK44 in blends with crystal polystyrene or styrene acrylate copolymers provide parts with exceptional clarity and toughness.

These grades contain a microcrystalline wax which acts as an anti-block. While the wax provides processing benefits, it does make these copolymers difficult to decorate. KR05NW is the no-wax form of KR05 to facilitate printing and decorating.

Sheet Extrusion

Polymer Blends

Blending K-Resin® SBC with other resins can satisfy the performance requirements of a broad range of applications. The most popular blend is with crystal polystyrene (PS), used for disposable, clear containers. K-Resin® SBC/PS blends balance the toughness of K-Resin® SBC with the stiffness and lower cost of PS.

The best blend ratio for an application is primarily determined by part design. Since biaxial orientation during the forming process increases part toughness, shallow draw parts like lids require higher K-Resin® SBC content than do deep draw parts such as disposable cups. For many K-Resin® SBC/PS parts, K-Resin® SBC content will be in the 40 – 75% range. When blending PS with K-Resin® SBC, compatibility is critical. The most commonly selected PS grades for blending have melt flow values between 3 and 12 g/10 min. Lower flow PS resins can cause increased melt temperature and promote degradation and haze problems. A low flow PS resin can also reduce the mixing efficiency of the screw and cause poor sheet clarity. Crystal polystyrene resins with melt flow values higher than 12 g/10 min usually mix well and provide good clarity; however, the sheet and formed parts may experience some loss of impact strength.

Equipment

Most sheet extrusion lines designed for styrene based polymers can be used for production of K-Resin® SBC sheet. Proper screw design, however, is critical to successful extrusion, since low compression can cause air entrapment and promote poor mixing. High shear screws, on the other hand, often cause excessive melt temperatures, resulting in thermal degradation. Sheet problems associated with excessive shear may include gels, haze and roll blockage.

Screw Design

Three general types of screws are used for the majority of K-Resin® SBC sheet extrusion.

The three typical categories include:

1. Relatively low compression screws designed for high density polyethylene (HDPE) or vinyl sheet extrusion
2. Medium compression screws specifically designed for K-Resin® SBC sheet extrusion
3. Higher compression screws designed to extrude high impact polystyrene (HIPS) sheet

A medium compression screw for K-Resin® SBC will maximize extruder output without compromising part clarity or performance. If a screw that processes a wider range of material is desired, process conditions can be modified to minimize problems. Specific extrusion parameters for the different screw design categories are discussed in the processing section of this bulletin.

Several manufacturers make screws suitable for K-Resin® copolymer sheet extrusion. Although many of the screws are quite dissimilar, extruder output may be roughly approximated with the following equation.

$Q = kD2Hn$
where: Q = output, pounds/hour
k = constant
D = screw diameter, inches
H = metering depth, inches
n = screw speed, rpm

For K-Resin® SBC, the constant "k" is approximately 2.5. Depending upon the specific design parameters and condition of the screw, actual output will vary from the estimated value. Chevron Phillips Chemical's Plastics Technical Center representatives can suggest sources for suitable screws for K-Resin® SBC production.

Sheet Dies

Although rigid-lip dies can be used to extrude K-Resin® SBC sheet, flex-lip designs offer improved gauge control. A flex-lip die with a restrictor bar is the most versatile in thin sheet applications. The restrictor bar helps equalize internal die pressures and melt velocity upstream of the die lips. Since die lip pressures are better controlled, melt flow from the die is more uniform.

K-Resin® SBC sheet duplicates the detailing of all surfaces contacted in the melt phase. Therefore, to minimize die lines, internal die surfaces should be chrome plated, highly polished and free of nicks.

Polish Rolls

Dirty spots on the polish rolls will be reproduced in the sheet, causing dull areas with reduced clarity. To prevent sheet imperfections, polish rolls should be chrome plated and highly polished. Each polish roll should be individually controlled by a heat exchanger capable of maintaining surface temperatures up to 160°F (93°C).

Slitters

K-Resin® SBC sheet can be slit to width using conventional razor blade slitters. To prevent edge cracking, the blades should be kept sharp and aligned parallel to the sheet's direction of travel. When extruding K-Resin® SBC /PS blends, especially when the PS content has been maximized for deep draw applications, the slitter mechanism should be positioned fairly close to the polish rolls in order that sheet can be trimmed while warm.

Processing

K-Resin® SBC are safe and easy to extrude because of their good melt strength and non-corrosive nature. Although degraded K-Resin® SBC pose no threat to the operator or equipment, excessive shear and melt temperatures can reduce sheet clarity. This section will detail process recommendations to optimize the clarity and impact resistance of the sheet.

Startup and Shutdown Procedures

The extruder barrel, transition sections and die should be soaked at about 350°F (176°C) prior to extruder startup. K-Resin® SBC are likely to degrade if allowed to stagnate at higher temperatures. Higher soak temperatures can cause thermal cross-linking and gels to form. A high concentration of gels in one area of the sheet can cause an 'applesauce' or mottled sheet surface. Once created, gels tend to get larger or break into many smaller gels on subsequent passes through the extruder – they do not re-melt or break down.

When the system reaches 350°F (176°C), the temperature settings may be increased to operational settings and sheet extrusion begun. If the extruder must be shut down at process temperatures for more than a few minutes, gels may be generated. If significant K-Resin® SBC degradation does occur in the extruder barrel and/or die, the equipment should be disassembled and cleaned. Chevron Phillips Chemical Company produces a concentrate (SKR 19) which contains a thermal stabilizer, when added at 0.5% or less, allows K-Resin® SBC to be less sensitive to thermal degradation.

Shutdown procedures are similar. The temperatures of all the components should be reduced to 350° F (176°C). Once this temperature is achieved, the extruder should be operated at 5 – 10 rpm until the entire system cools. The extruder can then be turned off without degrading the resin. Another successful technique is to purge in 100% PS at operating conditions, then the extruder can be turned off.

These procedures should be followed closely. If material is not moving through the system, all metal surfaces should be at or below 350°F (176°C). If surfaces are hotter when the extruder is off, PS should be purged in to prevent resin degradation. Once the extruder is restarted, K-Resin® SBC can be reintroduced and will easily push out the PS.

Melt Temperature

Proper melt temperature is a critical factor in K-Resin® SBC sheet extrusion. To prevent resin degradation, the melt temperature should be maintained below 425°F (218°C). Chevron Phillips Chemical Company produces a concentrate (SKR 19) which contains a thermal stabilizer, when added at 0.5% or less, allows K-Resin® SBC to be less sensitive to thermal degradation.

Extrusion Temperature Profiles

As discussed in the screw design section, several types of screws may be used for K-Resin® SBC sheet extrusion. A typical temperature profile for a system with a medium compression K-Resin® SBC screw would have the feed zone of the barrel set at 350°F (177°C), the second barrel zone set at 380°F (193°C), the third barrel zone set at 390°F (199°C) and all subsequent barrel, transition section and die zones set at 400°F (204°C). Optimum temperatures will probably vary slightly from these "starting temperature" recommendations.

Low compression screws can cause air entrapment in the melt and poor mixing of blends. These problems are sometimes resolved by increasing the temperatures on the first three barrel zones to enhance melting, and lowering the last two barrel temperatures and all die temperatures to increase head pressure. Tighter screen packs may also prove effective. High compression screws can sometimes cause excessive shear, which can cause polymer degradation.

Die Conditions

Sheet gauge should be controlled by adjusting die or restrictor bar bolts. Attempts to control material flow by strongly varying die temperature settings will meet with marginal success since sheet orientation and part strength will vary across the web (sheet width). Brittleness problems may occur when PS content in blend applications is maximized in order to minimize material costs. As stated earlier, the biaxial orientation experienced in thermoforming increases part strength. However, machine direction orientation from sheet extrusion reduces sheet and part strength and promotes cracking across the sheet's web. Optimum resistance to cracking is achieved by holding the die opening and sheet orientation to a minimum. This can be accomplished by setting the die opening about 5 – 10% larger than the required sheet gauge.

Polish Rolls

Optimum sheet polish and clarity is realized by setting the primary and secondary nips at the required sheet gauge. This practice provides adequate material to the polish roll nips so that sheet gauge can be maintained. Although the nips should be full, excess material behind the rolls (melt bank) must be avoided to prevent sheet stresses and loss of impact resistance. Polish roll temperatures can significantly affect sheet clarity. As with most polymers, K-Resin® SBC will stick to hot rolls; cold rolls may cause pock marks. The best starting point for all roll temperature settings is 160°F (71°C) with adjustments made as needed.

Winding

Although many parts made of K-Resin® SBC are thermoformed in-line, a significant portion are formed from roll stock. As with any sheet material, K-Resin® SBC sheet blends should be wound at a temperature lower than its heat deflection temperature. It should be free of gauge bands and wound just tight enough to prevent telescoping. If these guidelines are followed, roll blockage should not occur.

Drying

Since they are not hygroscopic, K-Resin® SBC do not usually require drying. They can, however, collect surface moisture if stored under humid conditions. When extruding sheet thinner than 30 mils (0.76 mm), moisture problems are extremely rare. The pressure generated by the extruder prevents moisture from passing the first compression section of the screw. As sheet gauge increases, head pressure is reduced. The resultant low extruder pressures increase the risk of moisture problems. Moisture problems are indicated by pits or silvery streaks in the sheet, along with die-face buildup and steam exiting the die.

Moisture related problems can be addressed by reducing the die opening to the suggested setting or by adding more restrictive screens which will elevate the pressure at the extruder head. If the problem persists, either the extruder should be vented or the resin dried at 150°F (66°C) for one hour in a desiccating dryer. Dryer air temperatures should not exceed 160°F (71°C) or the pellets will become tacky and block.

Purging

K-Resin® SBC sheet extrusion should be started using a clean die, extruder barrel and screw to prevent contamination and die line problems. While this procedure is typically followed for most clear sheet resins, production schedules frequently require that K-Resin® SBC and HIPS be extruded on the same equipment. Since they are very compatible with HIPS, either copolymer can be used to purge out the other if the equipment is reasonably clean. The K-Resin® SBC purge can be ground and added to future pigmented runs of HIPS sheet if desired.

Crystal polystyrene is also regularly used to purge K-Resin® SBC from extruders. The optimum purge technique depends on the individual plant's ability to reuse the blended materials.

There are a number of commercial purge compounds available. Although purge compounds do a very good job of cleaning the extruder and die, they cannot be pushed out with K-Resin® SBC within a reasonable period of time. If the equipment is dirty enough to require significant cleaning, disassembling and cleaning by hand is recommended in order to minimize downtime and costs.

Regrind

If the shear or thermal history is excessive, K-Resin® SBC will degrade during sheet extrusion, thermoforming and grinding operations. Most sheet plants, however, are able to utilize all of their regrind back into their normal production runs. Depending on its quality, regrind can be utilized by (1) adding as much regrind as part clarity requirements permit to the virgin resin, (2) running 100% regrind in less critical applications, (3) adding the regrind to HIPS sheet or (4) pigmenting the K-Resin® SBC regrind for use in selected HIPS applications. Most equipment used for grinding HIPS is suitable for grinding K-Resin® copolymers. When reprocessing K-Resin® SBC, a chopper with sharp blades, close blade clearance and adequate ventilation should be used to prevent thermal degradation and gel problems.

Thermoforming

Forming

K-Resin® SBC are easy to thermoform because they have good melt strength, draw well into relatively deep parts and transfer heat quickly, thus facilitating fast machine cycles. HIPS parts converted to K-Resin® SBC/PS blends are formed with very little change in oven heats, part shrinkage or production rates. The resultant parts are resistant to warpage and shrink approximately 0.005 to 0.008 in/in (0.5 – 0.8%).

Part Design

To prevent stress concentrations and cracking problems, sharp corners should be avoided. All radii should be at least equal to the starting sheet gauge. Deep draw parts should be designed with at least 3° of draft, particularly when blends of high PS content are used. Part stiffness and appearance can be enhanced by using ribs.

Molds

To optimize heat transfer and part production rates, machined aluminum is typically used for thermoforming K-Resin® SBC parts. To maximize part clarity, mold cavities should be highly polished. Grit-blasted mold surfaces will cause a significant loss of clarity. Grit-blasted surfaces can be used in combination with polished ones to provide highlighted areas of reduced clarity and create a unique look in the thermoformed part.

The mold must be well vented to prevent trapped air. Air entrapment will cause a slight dimpling of the part surface and reduce part clarity. If venting is achieved with vacuum holes, the drill bit should be no larger than #80. Effective mold venting can also be achieved by using vent slits of approximately 3 mils (0.08 mm). Flat surfaces can be “glass beaded” to ensure good contact for part cooling.

Mold temperatures are normally set between 70–150°F (21–66°C). Cold molds optimize part cooling and production rates; warm molds optimize surface smoothness and part clarity. The best K-Resin® SBC mold temperature for many operations is about 100°F (38°C). To promote even part cooling and prevent part warpage, mold cooling must be uniform. Manifolds must be designed to provide uniform water flow from the heat exchanger. Although acceptable manifold designs are almost infinite, the mold surface temperature should not vary more than 4°F (3°C) during production. Particular care should be taken to provide uniform cooling to the flat areas between mold cavities. This will make the web more uniform and improve trimming accuracy.

Plug Assists

In order to prevent chill marks and sticking, plug assists should be made from low heat transfer materials, have a smooth surface finish with no imperfections and possess good release characteristics.

Polytetrafluoroethylene (PTFE), polysulfone and syntactic foam are often selected for plug assists because they do not require heating. Heated aluminum plugs coated with PTFE can be utilized, but they are difficult to maintain at constant temperature due to their sensitivity to air drafts and hot spots from heaters.

Processing

K-Resin® SBC sheet has been thermoformed on solid phase pressure forming machines, oriented polystyrene (OPS) equipment with contact heaters, rotary, shuttle and single-station thermoformers. However, to maximize production rate, the bulk of K-Resin® SBC applications are formed on either in-line or roll-fed thermoformers.

Heating

Forming K-Resin® SBC sheet at about 275°F (135°C) achieves the best balance of part clarity, reproduction of mold detail and part wall distribution. Generally, sheet temperatures colder than 250°F (121°C) or hotter than 300°F (149°C) are unsuitable for thermoforming.

Most sandwich type infrared heaters are appropriate for thermoforming operations. Cal rod heaters can be utilized, but ceramic or quartz elements offer improved control of sheet temperature and cavity-to-cavity part uniformity.

Forming

K-Resin® SBC sheet can be thermoformed using any conventional technique. The most common techniques include male or female drape for shallow draw parts like lids and plug assist forming into female molds for cups and other containers. Cycle times and formability are similar to those of PVC and HIPS.

Part Ejection

Since molds for K-Resin® SBC production are highly polished, the vacuum between part and mold must be relieved by injecting air into the vent system. This is particularly important to prevent cracking problems in deep draw parts of K-Resin® SBC/PS blends. Excess use of air eject, however, can cause part breakage or deformation problems. Parts containing undercuts or very low draft angles may require stripper plates for successful release from the mold.

Printing and Decorating

K-Resin® SBC are difficult to print since they contain a wax which blooms to the surface. The wax can be removed from the surface of thin parts (sheet and film) by using corona discharge. Wax can be removed from thicker molded parts (bottles) using flame treatment or by wiping the surface with isopropyl or methyl alcohol. When treating K-Resin® SBC, the treatment should increase the surface energy to greater than 40 dynes. None of these treatments are permanent since the wax will re-bloom to the surface of the part. While the rate of migration is dependent on storage conditions, it is best to decorate the part within 48 hours of surface treatment.

Packaging Applications

K-Resin® SBC can be successfully utilized to package a broad range of products. Caution should be exercised, to prevent K-Resin® SBC or a K-Resin® SBC/PS blend from being used in an application for which it is not suited. K-Resin® SBC are subject to stress cracking if exposed to severe stress crack mediums. Sheet orientation, the depth of draw of the part, thermoforming conditions and part design and configuration affect their stress crack resistance. Stress cracking in food packaging applications is related to the stress crack medium, storage conditions and usage conditions of the container. High fat and oil content foods have the capability of stress cracking K-Resin® SBC. It is the ultimate responsibility of the end user to determine the safety and suitability of their product in which a K-Resin® SB Copolymer is a component.

Trimming

Parts made of K-Resin® SBC can be trimmed from the web using either steel-rule dies or punch and die sets. Punch and die sets are preferred for high speed production as they are self-aligning with the part.

New trim tools for HIPS generally have about 3 mils (.08 mm) clearance between the punch and die. The dies are soft (R38) so they can be easily preened back to size. The punches have a higher Rockwell hardness rating (about R62) for durability.

To ensure burr-free parts, trim tools for K-Resin® SBC are designed with much tighter clearances, usually 1 mil (0.03 mm) or less between the punch and die. Since tight clearances promote faster tool wear, dies for K-Resin® SBC are hardened to about R58. Punches should be hardened to R62. Old or poorly maintained trim presses and tight trim tool clearances can cause tool registration problems and tool damage.

Troubleshooting Guide

Even in the best of operations, occasional problems develop. The most likely difficulties that may occur are listed on the following pages, with probable causes and solutions.

Sheet Extrusion Troubleshooting Guide

Problems	Possible Causes	Suggested Solutions
Applesauce, gels, poor sheet clarity	1. Melt Temperature too high	1. Reduce melt temperature. a. Correct malfunctioning thermocouple and controllers. b. Reduce temperature settings. c. Install a lower shear screw. d. Reduce head pressure by using a less restrictive breaker plate and screen pack. e. Use a higher flow GPPS resin for blends. f. Sharpen grinder blades and reduce blade clearance as needed.
	2. Excessive residence time at process temperature	2. Eliminate melt hangup. a. Change screw or temperature profile if material hangs in vent. b. Correct fit of transition sections so no ledges exist. c. Eliminate deckle bars or reduce and plate heater temperatures on die.
Black Specks	1. Foreign material	1. Eliminate source of problem. a. Use liners when storing resin or regrind in gaylords. b. Keep paper bag fibers out of resin.
	2. Degraded polymer	2. Disassemble and clean extruder barrel, screw and die to remove deposits.
Milky areas of poor clarity	1. Contamination by incompatible polymer	1. Prevent contamination. a. Clean loader, hopper and dryer. b. Purge extruder. c. Disassemble and clean barrel, screw and die if needed.
Bubbles in sheet	1. Air entrapment	1. Improve melting and mixing function of extruder. a. Increase head pressure by using a more restrictive breaker plate and screen pack. b. Set inverse temperature profile on extruder. c. Use a higher compression screw.
Silvery streaks	1. Moisture on resin	1. Prevent or remove moisture. a. Dry copolymer at 140°F (60°C) for one to two hours. b. Melt resin more efficiently per recommendations shown in "air entrapment" section above.
Dull surface over entire sheet	1. Poor polishing due to insufficient contact with chill rolls	1. Fill both nips to ensure contact. Do not, however, allow rolling bank of material to occur.
Dull surface in moving, diagonal bands	1. Nip pressure too low, so polish rolls move up and down	1. Provide force of at least 300 pli (pounds per linear inch) or 5 newtons per linear meter of sheet width to hold rolls steady. Repair damaged or leaking polish roll cylinders as required.
Dull surface areas in transverse direction with sheet width varying	1. Extruder output surging	1. Provide uniform melting and material feed. a. Ensure regrind/virgin ratio is consistent. b. Cool feed zones & hopper zone to prevent bridging. c. Invert temperature profile if head pressure is lower than 1000 psi (7.0 Pa). d. Check operation of all heaters, thermocouples and controllers. e. Eliminate extruder drive and line speed variations. f. Change extruder screw or evaluate different GPPS for blending.

Sheet Extrusion Troubleshooting Guide

Problems	Possible Causes	Suggested Solutions
Dull surface areas in machine direction	1. Varying sheet gauge	1. Adjust gauge. a. Line out sheet die. b. Fix faulty heaters, thermocouples and controllers in die. c. Eliminate air currents or uneven die heat profile.
	2. Polish rolls have poor TIR (tolerance in radius)	2. Repair as needed.
Edge curl or poor sheet flatness	1. Polish roll temperatures not balanced	1. Correct with roll temperature. Sheet will move toward a roll as heat is increased and away from it as it is cooled.
	2. Non-uniform roll temperature	2. Maintain temperature variation across polish roll surface to less than 5°F (3°C). a. Increase system pressure and coolant flow rate to manufacturer's design recommendations. b. Remove scale by acidizing rolls as needed.
	3. Uneven heat transfer	3. Increase sheet tension to improve contact with polish rolls.
Surface scratches or lines in the machine direction of extrusion	1. Charred resin on die lips	1. Scrape die with brass tool. Do not use hard steel or damage to die surfaces may result.
	2. Scratched, burred or dirty die	2. Clean and repair die sections as necessary.
	3. Scored polish rolls	3. Polish or resurface roll face.
	4. Moisture in sheet (sheet will have silvery cast)	4. Dry resin.

Thermoforming Troubleshooting Guide

Problems	Possible Causes	Suggested Solutions
Lines and bands in the transverse direction of extrusion	1. Excess molten material in polish roll nips	1. Adjust sheet gauge and polish roll openings to just provide enough material to fill nips.
	2. Sheet sticks to polish rolls	2. Improve cooling. a. Reduce polish roll temperature. b. Eliminate thin spots in sheet. c. Improve sheet contact with polish rolls by increasing line tension. d. Ensure nip gaps are the same on both sides of the sheet. e. Reduce melt temperature.
Webbing	1. Sheet too hot	1. Reduce oven temperature or cycle time.
	2. Inadequate vacuum to evenly draw sheet	2. Add vacuum holes in problem areas.
	3. Excessive draw	3. Improve molding technique or part design. a. Use plug or ring assist. b. Use web blocks to minimize sag problems. c. Redesign mold to improve cavity spacing or balance draw.
Excessive sheet sag	1. Sheet too hot	1. Reduce oven temperature or cycle time.
	2. Oven too wide	2. Reduce melt flow of GPPS for blend or run on a more narrow thermoformer.
Uneven sag	1. Sheet temperature not uniform	1. Eliminate air drafts in oven and fix faulty heaters.
Part sticks to mold	1. Part temperature too hot for proper release	1. Reduce part temperature. a. Increase cooling cycle. b. Reduce sheet temperature. c. Lower mold temperature.

Thermoforming Troubleshooting Guide

Problems	Possible Causes	Suggested Solutions
Stretch marks on part	1. Plug assist sticks to sheet and causes freeze-off lines	1. Eliminate sticking. a. Change heated plug temperature to equal sheet temperature. b. Apply release coating to plug assist. c. Use lower stick material for basic plug construction.
	2. Cold mold causes curved chill lines around lip of part	2. Increase mold temperature or increase air cushion as part is formed.
	3. Mold temperature varies between cavities	3. Increase number of water channels or clean out plugged channels as necessary.
Nipples on mold side of thermoformed part	1. Sheet too hot	1. Reduce sheet temperature.
	2. Vacuum holes too large	2. Plug holes and redrill with #80 drill bit.
Pock marks	1. Air entrapment between part and mold	1. Eliminate trapped air. a. Slightly roughen large, flat mold surfaces with very fine grit blasting or glass beading of problem area. b. Clean out plugged vacuum holes. c. Add vacuum holes or vents as required.
Poor part detail	1. Cold sheet	1. Increase sheet temperature.
	2. Sheet temperature not uniform	2. Eliminate air drafts in oven, screen oven heat and add clamp rail heaters as needed.
	3. Inadequate vacuum on part	3. Improve contact with mold. a. Fix vacuum leaks. b. Clean plugged vacuum holes and vents. c. Add vacuum holes or vents in problem areas. d. Add moat or ring assist to ensure good seal around perimeter or part. e. Make sure surge tank and vacuum pump are large enough to quickly evacuate the mold.
Poor wall distribution	1. Sheet temperature not uniform	1. Use screens, additional heaters or eliminate air drafts in oven.
	2. Poor mold design	2. Reduce severe areas of draw, increase draft angles and reduce undercuts in mold.
	3. Sheet drags on mold lip during plug-assist forming	3. Increase air cushion under sheet during plug assist travel. a. Increase plug speed. b. Reduce vacuum bleed rate. c. Reduce vacuum hole size. d. Raise mold surface around lip of part so sheet drag on lip is reduced.
Part warpage	1. Mold too hot or cold	1. Try setting mold temperature at 100°F (38°C).
	2. Uneven mold cooling	2. Clean plugged water channels or add channels as needed.
	3. Poor part wall distribution	3. Improve wall distribution as suggested in previous troubleshooting section above.
	4. Part not cooled adequately	4. Increase cooling cycle time, reduce mold temperature or reduce sheet temperature.
	5. Poor mold contact	5. Improve vacuum on part (see section under "Poor part detail").
	6. Part design not rigid enough	6. Add ribs and additional detail where possible.

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ISO 9001:2000
Certificate Number: 30269

This product was manufactured in a plant whose quality management system is certified or registered as conforming to the requirements defined in the ISO 9001 Standard.

August 2008