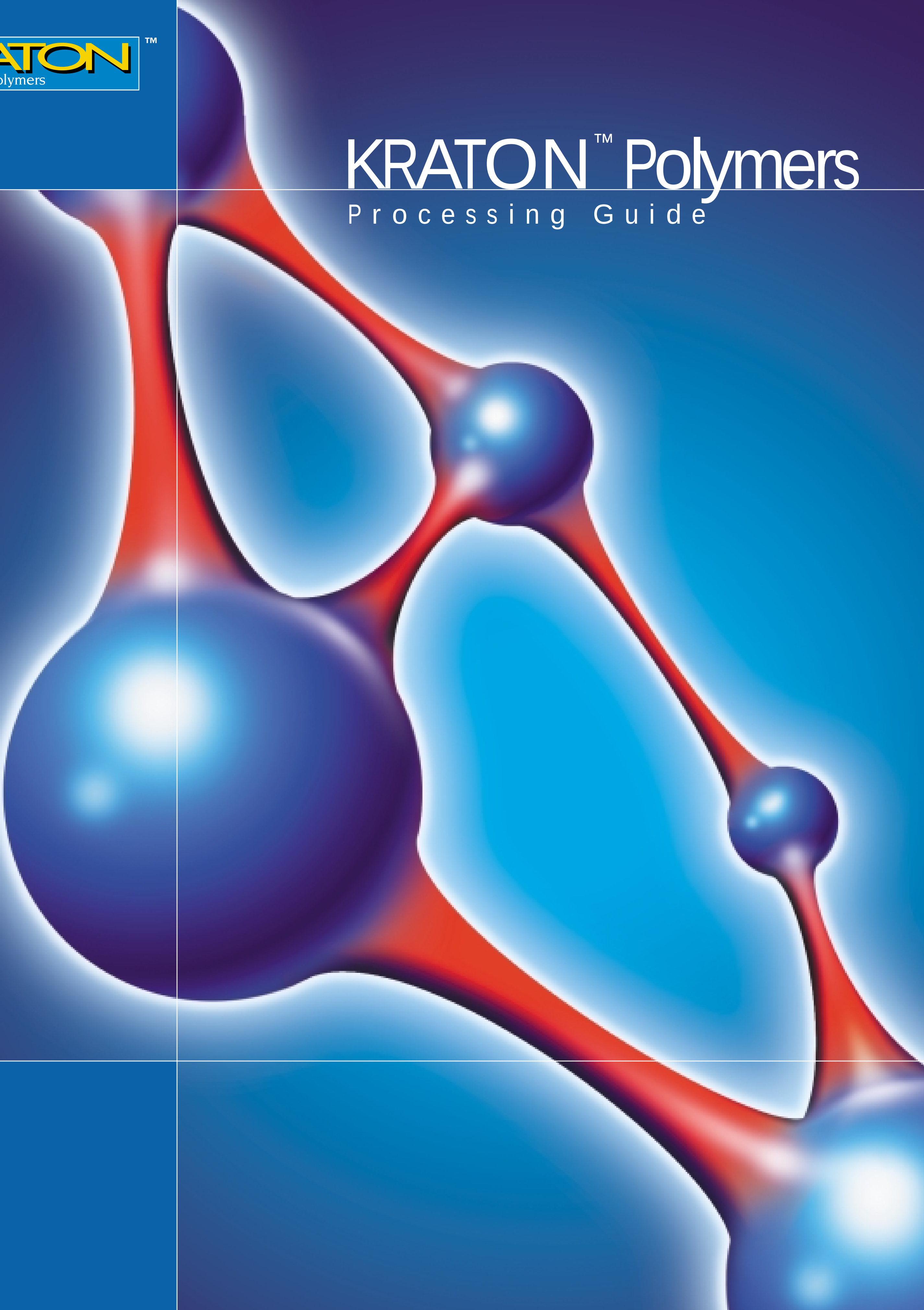
KRATON™ Polymers

KRATON™ Polymers

Processing Guide



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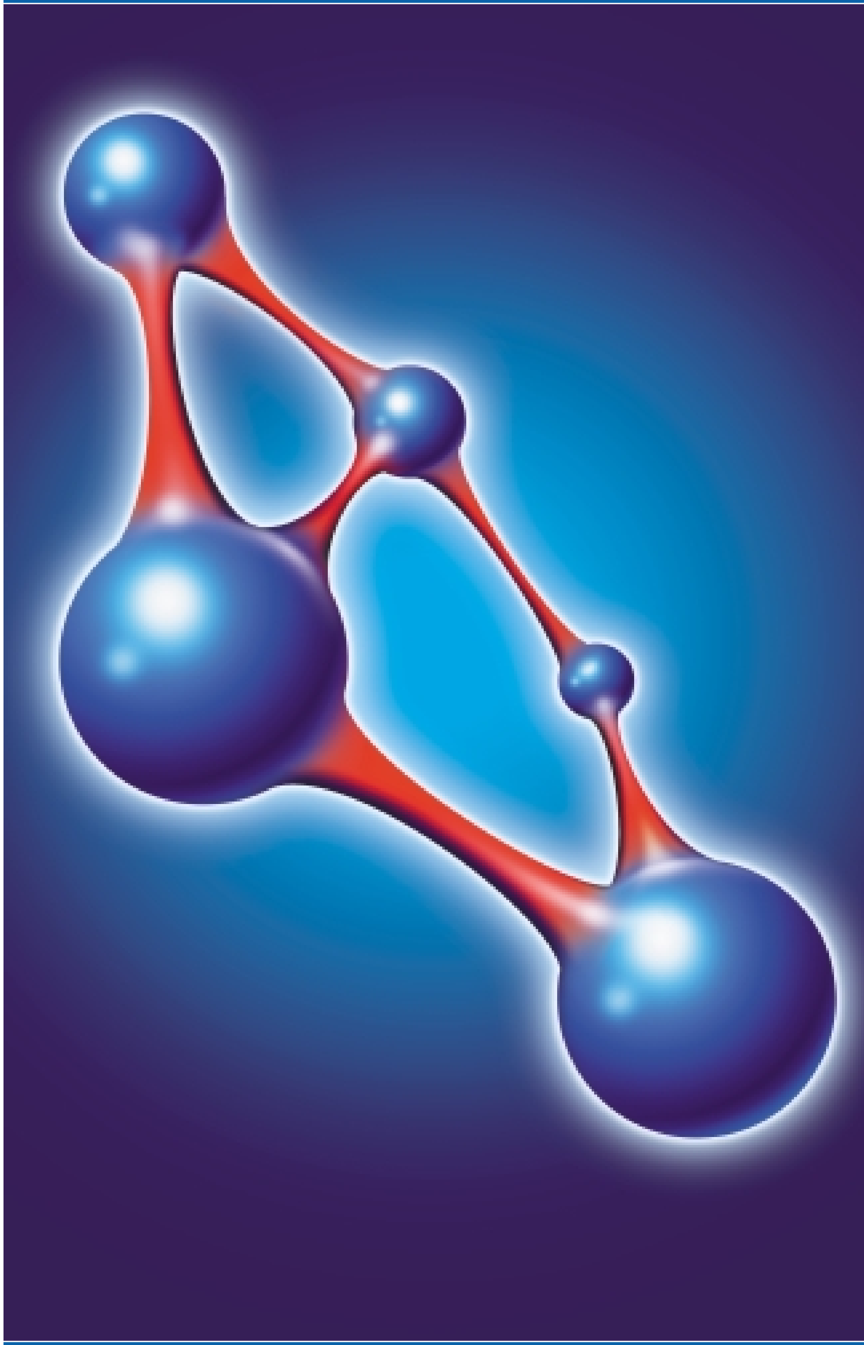
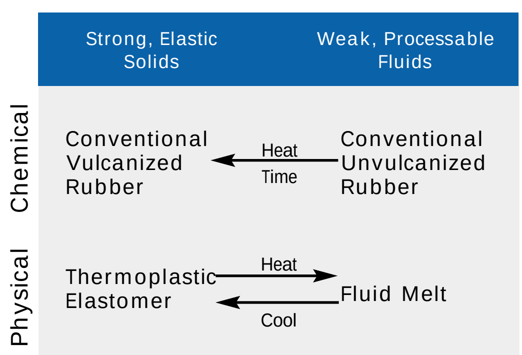


Introduction

KRATON™ Polymers are a series of synthetic elastomers that combine the properties of vulcanized rubber with the processing advantages of conventional thermoplastics. In other words, they allow the production of rubber-like articles using the fast processing equipment developed by the thermoplastics industry.

Figure 1:
Comparison of conventional and thermoplastic elastomers



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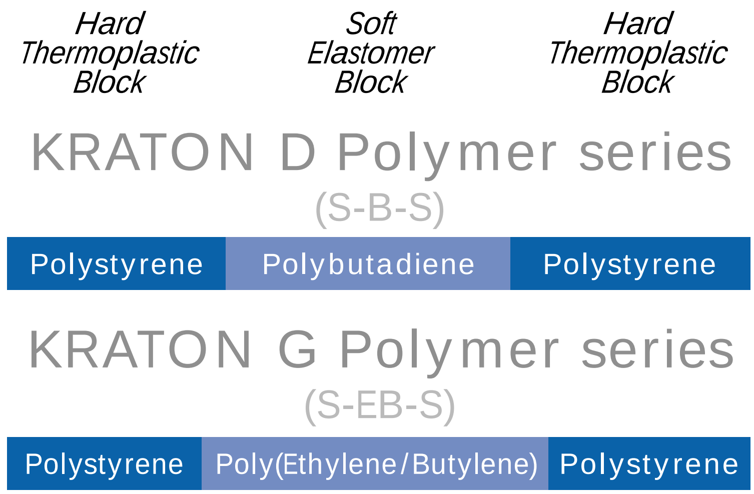
Block Copolymer Structure

The block copolymer structure of KRATON™ Polymers gives them a useful range of properties. Their chemical make-up consists of three discrete polymer blocks of the A-B-A type. The end blocks (A) are a hard thermoplastic (polystyrene) while the center blocks (B) are elastomers. Two elastomers are commonly used in the products discussed in this Processing Guide: poly(butadiene) and poly(ethylene / butylene). The first gives block copolymers that are denoted as S-B-S. These constitute the first generation KRATON D Polymer series. Those based on poly(ethylene / butylene) are denoted as S-EB-S and constitute the second generation KRATON G Polymer series.



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At room temperature, the polystyrene endblocks are hard and strong, and lock the elastomer blocks in place to give a physically crosslinked network. It is this network which gives KRATON Polymers their elastomeric properties, comparable to those of conventional vulcanized rubbers. On heating, the polystyrene softens and the polymer is able to flow and be molded. When the molded product is cooled, the polystyrene becomes hard again, and the network regains its strength. Thus, this physical crosslinking of KRATON Polymers is a reversible process. This reversible behavior is shown diagrammatically in Figure 1, where it is contrasted to the irreversible process (vulcanization) that is used to make conventional rubber articles.

KRATON D and G Polymer Compounds

In nearly all end-use applications, KRATON Polymers are not used as pure polymers; they are compounded with other materials. To make compounds intended for use on the processing equipment developed by the thermoplastics industry, various materials such as oils, other polymers, fillers, and additives (i.e., antioxidants and pigments) are added to the S-B-S and S-EB-S base polymers. This compounding also presents the opportunity to produce materials with an exceptionally wide range of properties and optimized for specific applications. The key properties of KRATON Polymer compounds are identified in Table 1; technical bulletins on individual grades are also available. An overview of the KRATON Polymer Compound Grade Classification System is shown in Table 2.

KRATON D Polymer compounds have midblocks of an unsaturated elastomer, polybutadiene, and usually contain polystyrene as the added polymer. These polymer compounds are easy to process, moderate in cost, and are intended for less demanding applications.

KRATON G Polymer compounds have midblocks of a saturated elastomer, poly(ethylene / butylene), and usually contain polypropylene as the added polymer. These polymer compounds have the additional advantages of increased oxidation and weather resistance, improved solvent resistance, higher upper service temperature, and better processing stability.

Produced in pellet (nib) form, KRATON Polymer compounds eliminate the need for mastication, dicing, or grinding. They can easily be used for dry blending with other pelletized materials.

A wide variety of articles can be made from KRATON Polymer compounds by using conventional molding, extrusion, or other forming techniques familiar to the thermoplastics industry. However, there are some differences in the processing behavior of these materials relative to other thermoplastics which necessitates minor modifications in mold and die designs and in processing conditions to achieve optimum performance. Furthermore, differences in the structures, characteristics, and physical properties of the unsaturated and saturated rubber midblocks (See Table 3) lead to differences in optimum processing conditions between KRATON D and G Polymer compounds.

The purpose of this processing guide is to indicate the processing conditions and techniques that are appropriate for each of these two classes of KRATON Polymer compounds when fabricated by typical thermoplastic processing techniques. The suggestions which follow are predicated on our research and development efforts, and are the results of over 25 years of field experience.

Table 1:
KRATON Polymer compounds – key properties

KRATON D Polymer Compounds	KRATON G Polymer Compounds
• *Elasticity* / • *Flexibility* } *"Rubberiness"* • *Wide Property Range* • *Easy Processing* • *Economic Advantage of Thermoplastic Processing* • *Reprocessable*	• *Elasticity* / • *Flexibility* } *"Rubberiness"* • *Wide Property Range* • *Easy Processing* • *Economic Advantage of Thermoplastic Processing* • *Reprocessable* • *Higher Upper Service Temperature* • *Improved Weatherability* • *Improved Processing Stability* • *Improved Solvent Resistance*

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Table 2:
KRATON Polymer compounds – grade classification

End Use Application	KRATON D Polymer Compounds	KRATON G Polymer Compounds
Food and Drug	*2100*	*2700*
General Purpose	—	*7000*
Automotive	—	*7000*

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Table 3:
Comparison of KRATON Polymer compounds

	KRATON D Polymer Compounds	KRATON G Polymer Compounds
End Blocks	*Polystyrene*	*Polystyrene*
Center Blocks	*Polybutadiene*	*Poly(ethylene / butylene)*
Weather and Oxidation Resistance	*Moderate*	*High*
Processing Stability	*Good*	*High*
Normal Processing Temperatures		
°F	*300 – 390*	*375 – 500*
°C	*150 – 200*	*190 – 260*

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Figure 2:
Viscosity/shear rate relationships 390 °F (200 °C)

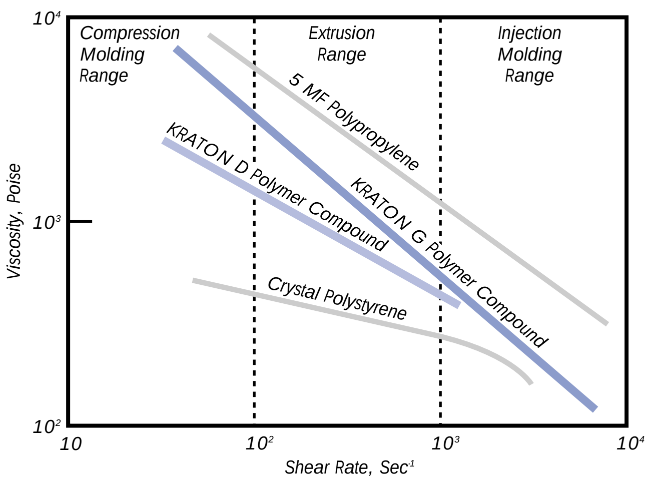

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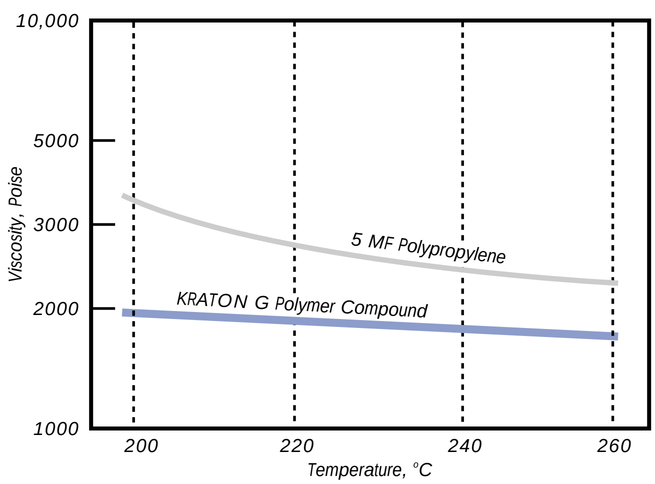
Figure 3:
Viscosity/temperature relationships (200 sec^{-1})



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Stability

KRATON™ D Polymer compounds with unsaturated midblocks are susceptible to oxidation, and so degradation can occur at excessively high temperature and shear conditions. To minimize this degradation, the recommended processing temperature range is from 300-390 °F (150-200 °C). Molten material should not be allowed to sit in the processing equipment for long time periods. It is also desirable to maintain shear rates in the lower range of the respective thermoplastic processes. If degradation does occur, gel particles can be produced and, in extreme cases, gelation can occur. Thus, increasing the melt temperature beyond approximately 390 °F (200 °C) can increase melt viscosity and reduce output.

In contrast, KRATON G Polymer compounds with saturated elastomer midblocks are considerably more stable to oxidation at higher temperatures and shear rates. The normal processing temperature range is from 375-500 °F (190-260 °C). These polymer compounds are often processed at higher shear rates.

Rheology

Because of the different chemical structures of the two elastomeric midblocks, the viscosity/shear rate characteristics of these two families of KRATON Polymers differ. Their relative relationships are illustrated in Figure 2, where they are also compared to other polymers. The melt viscosity of these materials is very responsive to shear. However, it is relatively insensitive to temperature, especially with the KRATON G Polymer compounds, as shown in Figure 3. The unsaturated KRATON D Polymer compounds do not require high shear rates to attain low viscosity and easy thermoplastic flow. The viscosity of KRATON G Polymer compounds, however, falls much more rapidly with shear rate. Thus, optimum flow during the processing of these polymer compounds requires a higher shear rate. As the curves in Figure 2 suggest, moderate injection rates during injection molding and low compression ratios on extrusion screws are preferred for KRATON D Polymer compounds. Conversely, fast injection rates and high compression ratio extruder screws are preferred for KRATON G Polymer compounds.

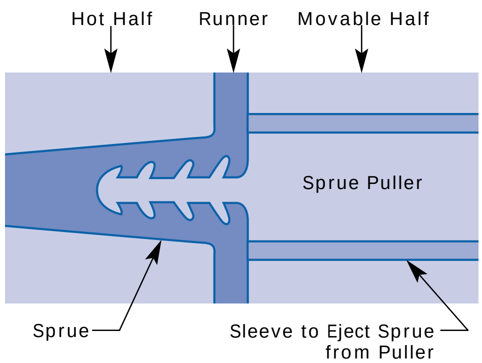
The physical properties of KRATON Polymer compounds are sensitive to processing conditions and processing equipment. Therefore, it is most important to make test samples under conditions and on equipment similar to those being used in production. Misleading results will be obtained if, for example, prototype parts or test pieces are compression molded when the actual products will be made by extrusion or injection molding. The most meaningful results will be obtained on test pieces taken from actual production parts.

KRATON Polymer compounds are anisotropic and show the effects of molecular orientation under normal processing conditions. This orientation is a function of the shear applied to the molten polymer, and is manifested by greater stiffness and modulus in the direction parallel to flow. Orientation effects may be reduced by adjusting processing conditions so as to minimize shear; this may be accomplished by decreasing screw speed and / or injection rate. However, excessive reduction should be avoided since it may result in flow problems. Another alternative is to increase the processing temperature of the polymer and / or mold temperature. This increased processing temperature often improves the physical properties of the final product.

Injection Molding

KRATON Polymer compounds can be fabricated by injection molding to form parts that have a high degree of elasticity and flexibility. It should be recognized, however, that these properties are also influenced by part design and flow patterns.

Figure 4:
Sprue design



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Machine and Mold Parameters

Types of Injection Machines

KRATON Polymer compounds are usually processed on conventional reciprocating screw injection molding machines. These machines provide lower operating temperatures and more uniform melt characteristics, which are desirable for most thermoplastics. In addition, the high-shear-rate turbulence developed in the melt zone is beneficial to fast, uniform injection.

Screw Design

Most reciprocating screw injection molders are equipped with general purpose screws with compression ratios of 2:1 to 3:1, 60° tip angles, and some type of anti-back-flow mechanism. Screws of this type are typically used to process PVC and polyolefins, and are suitable for use with KRATON Polymer compounds. Special screws with short sections of higher compression ratios (3:1 to 4:1) also may be helpful at low screw speeds. Two-stage vented screws are useful for removing any surface moisture that might be present in the KRATON Polymer compounds.

Nozzles

Conventional nozzles, nozzles with reverse tapers or nozzles employing some means of positive shut-off are equally acceptable for molding KRATON Polymer compounds. KRATON Polymer compounds have high viscosities at low shear rates and do not give volatile products on heating – thus, drooling at the nozzle is seldom a problem. Use of a permanent release coating (See section on Mold Surface Finish) on the inner surface of the nozzle will help prevent the sprue from sticking.

Sprues

Standard sprues with draft angles of at least 3° can be used for molding KRATON Polymer compounds. The low thermal shrinkage of KRATON D Polymer compounds also requires runners to be smooth. The type of sprue puller, however, should be considered for each grade of material. In general, "Z" type pullers will not be adequate for the softer grades of KRATON Polymer compounds. Undercut "fingers," reverse taper cold wells, and slot bar pullers are satisfactory for most grades (See Figure 4).

Runners

Large diameter, full-round runners are preferred for conveying the KRATON Polymer melt to the mold cavity. Other designs, such as half-round and trapezoidal, can also be used; however, they are not as efficient since they have more surface area than full-round runners of the same cross-section. Flat runners should be avoided since they may cause premature freezing of the melt, resulting in flow and sink marks. Secondary runners should be full-round and slightly smaller in diameter than the primary runner and branch off at right angles. Balanced flow is highly desirable, so secondary runners should all be the same length. Adequate cold slug pockets also should be provided where appropriate. Abrupt flow transitions (e.g., right angle bends) should be avoided in the region near the gate. A straight runner, whose length is at least double its diameter, should precede the gate.

To reduce cycle time and avoid regrinding of sprues and runners, insulated or heated runner systems may be used for parts having thin cross sections; valve gated systems often give good results. Hot tip systems also can be used, but may give some distortion in the gate area.

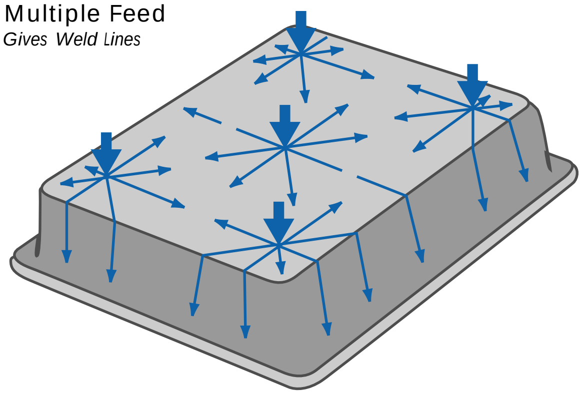
Hot runner systems, or hot-well cold runner systems should be larger than the cold runner systems to keep mold back-pressure constant. Minimum temperature of the runner core through the unloading cycles should be approximately 350 °F (177 °C) for KRATON D Polymer compounds and 375 °F (190 °C) for KRATON G Polymer compounds.

Gate Selection

KRATON Polymer compounds will mold well using common gate types consistent with conventional design practice. In general, the gate should be just large enough to fill the mold without causing degradation by excessive heat generation. Thickness of the gate should be about 15% to 25% of the part thickness at the gate location. The land length should be kept as short as possible while still maintaining efficient freeze-off. Good results are achieved with a fan or edge gate at one end of the mold. To reduce orientation, the gate should be located so as to give the shortest possible flow distance in the cavity. To prevent sink marks, the gates should also be located near to or into a thicker cross-section of the part. Pin gates give surface imperfections; these are minimized if the flow impinges on the opposite surface of the mold. Submarine gates work well and multiple gating reduces cycle time in large parts, but can give problems with weld lines. Weld lines (if present) and gates should be located in areas of the part that will not be stressed in service (See Figures 5a-c).

Figures 5a-c:
Injection molding gate locations

Multiple Feed
Gives Weld Lines



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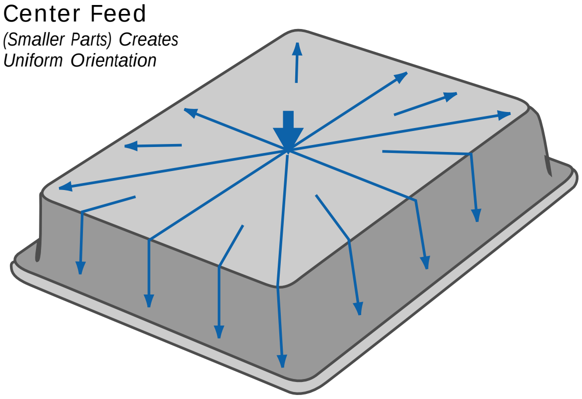
Center Feed
(Smaller Parts) Creates Uniform Orientation



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Side Feed
Creates Linear Orientation

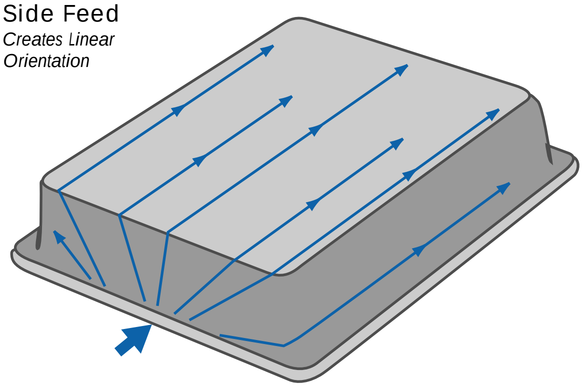

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Figure 6:
Mold design – avoiding sinks

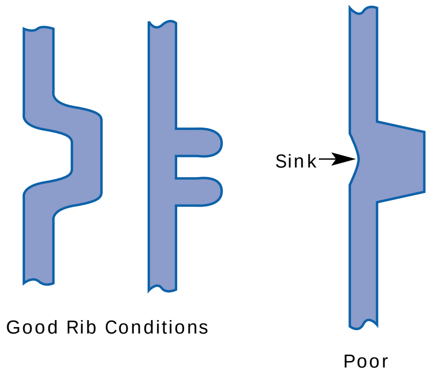

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Figure 7:
Air assist with mechanical stripper

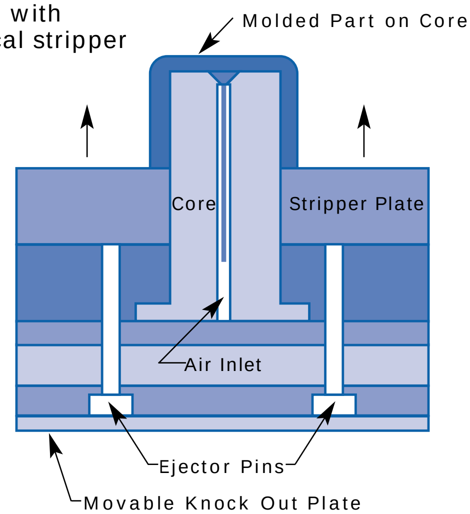

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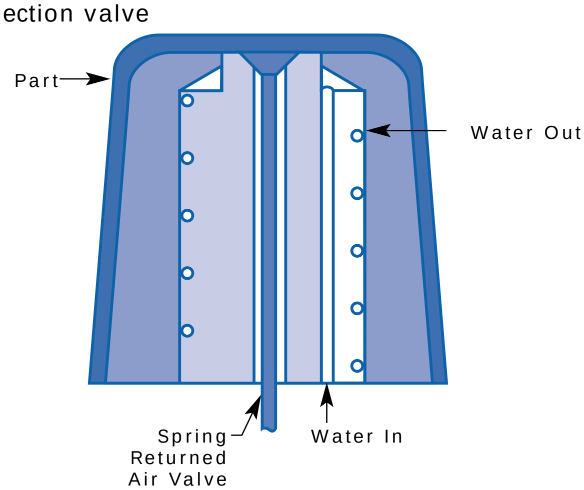
Figure 8:
Air ejection valve



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Mold Design

In general, abrupt changes in the flow pattern of the molten polymer will give surface imperfections. Thus, corners and transition zones should be radiused rather than sharp. Pins and other obstructions that will give weld lines should be avoided, if possible.

Sinks are the direct result of a non-uniform volume decrease when a molten part is cooled. With KRATON Polymer compounds, sinks in thin sections (<0.25") can usually be eliminated by controlling the holding conditions. Thicker sections can present more of a problem. In these cases, sinks can be minimized by judicious design of ribs and reinforcing sections in order to maintain uniform cross sections (See Figure 6).

Textured or matte-finished mold surfaces give the best results because they reduce the visibility of flow marks and provide for easier part ejection. Soft KRATON Polymer compounds often stick to the mold surface; vapor honing it or even using a #2 SPI finish reduces the problem. Another alternative is to treat the mold surface with a permanent release coating.

Mold Venting

KRATON Polymer compounds (especially KRATON G Polymer compounds) are often molded at fast injection rates. Thus, to avoid burning and streaking from vapor and moisture trapped in the cavity, good venting is needed. Vents measuring 1/4" x 0.0003" or 1/8" x 0.001" (6.35 mm x 0.00762 mm or 3.175 mm x 0.254 mm) should be satisfactory for small parts. They can be taper-ground or relieved directly to air after about 1/8" (3.175 mm). Sintered metal vents can also give good results. However, they usually leave a mark on the molded surface, and must be placed in an area where appearance is not critical. All of these vents will be even more effective if a vacuum can be applied to them while the mold is closed. The vents should be placed at the last part of the mold to fill. The exact location can be found by shooting "short shots."

Ejection

KRATON Polymer compounds usually have high surface friction, and some are soft and very flexible. These soft materials can be difficult to eject from the mold and, in this case, stripper plates are recommended for the most reliable part ejection. Air or air-assisted ejection is also useful (See Figure 7). Deep draw parts can often be ejected by air. Even when mechanical means are provided, incorporation of an air valve will serve to break a vacuum and assist in part ejection (See Figure 8). If ejector pins are used, they should be as large as possible and should push against sections of the part providing greatest support.

To provide the most trouble-free release, a textured or treated mold surface is strongly recommended. Additionally, a taper on all walls and cores is highly desirable. Draft angles should be at least 3°. With the stiffer KRATON Polymer compounds, most of the common ejector systems are satisfactory.

Undercut parts that would normally require slides or cam dies can often be molded on simple undercut dies by stripping or flexing the KRATON Polymer compound parts off the die. The elasticity of the molded parts offers many novel opportunities in design.

Mold Cooling

Molds should have ample coring for water cooling, and a provision for controlling the water temperature. This will give uniform heat removal, thereby minimizing cycle time.

Shrinkage

As with other thermoplastic materials, shrinkage characteristics should be considered when designing molds. The shrinkage of KRATON Polymer compounds is specific to each type, and ranges from about 0.005 to about 0.020 inches/inch (0.5 to 2.0%). Shrinkage is usually higher in the direction of flow in the mold. Generally, the KRATON D Polymer grades are in the lower end of this range, with the KRATON G Polymer grades being somewhat higher. Denser (i.e., filled) grades tend to not shrink as much as less dense grades. Shrinkage also varies with such parameters as mold temperature, melt temperature, injection rate, and part thickness. More specific shrinkage data is contained in the technical bulletins on the individual KRATON Polymer compound grades.

Molding Conditions and Considerations

KRATON Polymer compounds can be molded easily using normal machine conditions for thermoplastic processing. Some typical operating conditions are shown in Table 4. As with any thermoplastic material, the shape of the part and the design of the mold, as well as the molding conditions and polymer and compounds characteristics, influence the successful production of parts from KRATON Polymer compounds.

In the following section, recommendations are given for guidance, but in the final analysis, experience is the best guide for selecting specific molding conditions for any thermoplastic material.

Table 4:
Typical operating conditions for injection molding KRATON Polymer compounds on reciprocating screw machines

	KRATON D Polymer Compounds	KRATON G Polymer Compounds
Mold Type	2 Plate	2 Plate
Cavities	1	1
Shot Weight, Ounces	2	2
Cylinder Temperatures, °F (°C)		
Feed Zone	175 (80)	175 (80)
Center Zone	350 (175)	410 (210)
Front Zone	380 (195)	440 (225)
Nozzle	374 (190)	455 (235)
Mold Temperature, °F (°C)	75 (25)	125 (50)
Injection Pressure, psi[1] (MPa)		
High	700 (4.8)	700 (4.8)
Low	500 (3.4)	500 (3.4)
Injection Time, Seconds	3	1
Injection Rate	Moderate	Fast
Hold Time, Seconds	5	5
Clamp Time, Seconds	10	7
Screw RPM	30	40
Back Pressure, psi (MPa)	50 (0.34)	50 (0.34)
Cycle Time, Seconds	20	15

[1] These pressures are typical of those used with the more viscous KRATON Polymer compounds.

Cylinder Temperatures

For all KRATON Polymer compounds, the feed zone temperature should be between 150-200 °F (65-95 °C). For KRATON D Polymer compounds, the other temperatures should range from 300-390 °F (150-200 °C), with the temperatures increasing by about 45 °F (20 °C) from the zone next to the feed zone to the nozzle. Temperatures above 428 °F (220 °C) should be avoided for KRATON D Polymer compounds since degradation of the material may occur. Corresponding temperatures for KRATON G Polymer compounds are usually higher, typically 400-475 °F (205-245 °C) for normal sized parts, although temperatures approaching 500 °F (260 °C) may be required for large parts.

Molding parts at temperatures below the optimum leads to poor flow, formation of weld lines and pearlesence. In general, higher temperatures give better mold fill, as well as less orientation and better physical properties in the molded part. However, parts molded at higher temperatures require longer cooling times before they can be ejected from the mold, thus increasing the total cycle time. Higher temperatures can also give yellowing and odor in the final parts. These effects are caused by oxidation and can be reduced or eliminated by bleeding a stream of nitrogen into the feed hopper.

Injection Pressure

KRATON Polymer compounds can be molded over a wide range of injection pressures. Best results are obtained, however, when the minimum pressure required to smoothly fill the mold cavity is used. Depending on part size and surface area, injection pressures may vary from 500 to 1,000 psi (3.4 to 6.89 MPa).

Although the injection pressure required will vary with mold design and gate type, excess pressure often results in increased orientation effects or frictional overheating of the material. Also, because of the rubbery nature of KRATON Polymer compounds, gates do not freeze-off in the same manner as with rigid thermoplastics, and excessive injection or hold pressures may result in "after-fill" and consequent part distortion.

If high injection pressure is required to adequately fill the cavity, the boost time cycle should coincide as closely as possible with the time required for complete fill.

Injection Rate

The melt viscosities of KRATON Polymer compounds (especially KRATON G Polymer compounds) are highly dependent on shear rate (See Figure 2). KRATON D Polymer compounds are normally molded at moderate injection rates, but best mold filling with KRATON G Polymer compounds is obtained when parts are molded at relatively fast injection rates. These faster injection rates are desirable to prevent freeze-off during mold filling.

Air entrapment at fast injection rates should not be a problem if adequate venting is provided (See previous section on Mold Design). The cushion should be as small as possible to prevent post packing and scarring at the gate.

Screw Speed and Back Pressure

Typical screw speeds range from 25 to 75 rpm. The speed should be adjusted so the screw returns just before the mold opens. This procedure will not increase cycle time.

Low back pressures are suggested for KRATON Polymer compounds. Normally, 50 psi (0.34 MPa) will be sufficient to achieve a proper melt and consistent shot size. When using color concentrates or when blending two or more materials, higher back pressure is usually beneficial.

Hold Time and Pressure

As with most thermoplastic materials, to prevent sinks from back-flow at the gate or distortion from post packing, a balance must be obtained between hold time and pressure.

Because of the elastomeric nature of KRATON Polymer compounds and their rapid "set-up" rate, post packing is more likely to be a problem than back-flow. For this reason, short hold times and low hold pressures are suggested. A good way of optimizing the hold pressure is to reduce it to the point where sinks become apparent in the final part, then increase it in slight increments until they disappear. In machines with the capability to program hold pressure, it is good practice to "ramp down" the hold pressure so the final value is about one-half the initial value.

Clamp Pressure

KRATON Polymer compounds seldom require high clamping pressure. Depending on mold size and design, a range of 1.0 to 2.5 tons/square inch (0.25 to 0.75 tons/cm) should be enough to lock the mold and prevent flashing.

Clamp Time (Cooling Time)

Because of the rapid "set-up" inherent to KRATON Polymer compounds, only short clamp times are required. Clamp time is determined primarily by the hardness of the polymer compound and the part thickness.

The following ranges have been found typical:

Softer (<75 Shore A) KRATON Polymer Compounds

Sections up to 0.075" (1.905 mm): 20-30 seconds

Sections from 0.075" (1.905 mm) to 0.25" (6.35 mm): 30-60 seconds

Harder (>75 Shore A) KRATON Polymer Compounds

Sections up to 0.075" (1.905 mm): 15-25 seconds

Sections from 0.075" (1.905 mm) to 0.25" (6.35 mm): 25-45 seconds

These are only guidelines, however, as specific cycle times are dictated by mold design, part design, and processing conditions, especially processing temperatures.

Mold Temperatures

Optimum mold temperatures for KRATON D Polymer compounds are usually 50-105 °F (10-40 °C). KRATON G Polymer compounds should normally have higher mold temperatures in the range of 95-150 °F (35-65 °C). Higher temperatures assist in mold flow, can give complete filling at reduced injection pressures, and can produce more uniform surfaces with only minor increase in cycle time. They also can reduce orientation and provide for parts with better physical properties.

Downtime Purging

Since KRATON Polymer compounds have good heat stability, purging of the cylinder after cycle interruptions is usually not required. KRATON G Polymer compounds are extremely stable, and have been held in molding machines at processing temperatures for periods up to two hours with no evidence of degradation or machine damage. If purging is desired, polystyrene is recommended for KRATON D Polymer compounds, and high density polyethylene or polypropylene is recommended for KRATON G Polymer compounds.

Regrind

KRATON Polymer compounds are reprocessable. Sprues, runners, and improperly molded parts can be ground and blended with virgin material. For best results, no more than 25% of reprocessed KRATON D Polymer compounds should be used in the blend; KRATON G Polymer compounds can usually be reused in any proportion. Successful regrinding of soft and very flexible parts should not be difficult if it is remembered that the polymer must be cut rather than shattered. This means the cutter blades must be sharp and clearances minimized. Blocking of the chopped scrap can be reduced by tumbling with about 0.1% of a fine particle size re-precipitated calcium carbonate such as Albaglos™ (Pfizer) as soon as the grinding operation is finished.

If clarity of the final product is important, a fine particle size amorphous silica, such as Hysil™ 233 (PPG) can be used instead.

Drying

KRATON Polymer compounds do not readily absorb moisture under normal storage conditions, and so drying is not usually necessary. Some moisture may be found in products containing inorganic fillers, however, arising from moisture contained within the filler. Most of this small amount of moisture can be removed with the use of a two-stage vented injection screw (See previous section on Screw Design). The remaining moisture is usually volatilized in the mold and removed by proper venting. If the appearance of the molded parts is critical, it can often be improved if the pellets are dried in a hopper drier for about 2-4 hours at 125 °F (50 °C). Volatization of some moisture in specific inorganic fillers can be used to create a splashed or crepe-type effect on molded parts.

Note: KRATON Polymers and compounds can accumulate electrostatic charges when rubbed, chafed or abraded. Equipment should provide a means of dissipating any charges that may develop.

Coloring

Many KRATON Polymer compounds are available as either transparent or natural (i.e., slightly off-white) grades, which can be colored or pigmented, if desired. This is usually done by blending with color concentrates, using either in-line metering or dry tumbling. The color concentrates are pelletized dispersions of the colorants or pigments in a base polymer (the carrier resin). It is important to choose the correct base polymer, and this choice depends primarily on the type of KRATON Polymer compound being used. Color concentrates based on polystyrene or EVA are best for use with KRATON D Polymer compounds. For KRATON G Polymer compounds, color concentrates based on either polypropylene or polyethylene are appropriate, but those based on EVA lack sufficient thermal stability for this use. Concentrates based on PVC should not be used with any KRATON Polymer compound.

It is important to get a good dispersion of the concentrate in the final product. Higher screw speeds and higher back pressures are recommended for this purpose. Screws and/or nozzles with a mixing section will also help.

Extrusion

KRATON Polymer compounds can be extruded with almost any type of thermoplastic extruder if proper extrusion conditions are met. Profiles can be made successfully with simple slot or plate dies. Tapered and polished dies produce the best extrudates. KRATON D Polymer compounds can be degraded if overheated or if a screw having an excessively high compression ratio is used. To prevent contamination on start-up by foreign materials, or possible thermal degradation after prolonged shutdown, it is important to purge the extruder. Products similar to those recommended as the base polymers for color concentrates (See previous section) should be used. KRATON G Polymer compounds, with their saturated midblock composition, are much more stable and usually do not require purging after shutdown.

Extrusion of KRATON D Polymer Compounds

Screw and Die Design

Extruders used for processing KRATON D Polymer compounds should have a length to diameter ratio (L:D) of at least 20:1. The recommended screw design features include low compression ratios and rather deep flighted metering sections. Table 5 identifies typical design ranges for single and two-stage screws for extruding KRATON D Polymer compounds. Vented (especially vacuum-vented) two-stage screws are especially effective in preventing the formation of bubbles in the extrudate. The use of a screw with a mixing section (e.g., a Maddox head) or mixing pins often gives better dispersion of color concentrates and improves melt uniformity.

Table 5:
Typical screw configuration for extrusion of KRATON D Polymer compounds

Characteristics[1]	Single Stage	Two Stage
Length / Diameter (L:D)	24:1	24:1
First Stage		
Feed Section		
Flight Depth, Inch (mm)	0.450 (11.43)	0.500 (12.7)
No. of Flights	9	6
Transition Section		
No. of Flights	8	4
Metering Section		
Flight Depth, Inch (mm)	0.180 (4.572)	0.140 (3.556)
No. of Flights	7	4
Compression Ratio	2.5:1	2.5:1
Second Stage		
Feed Section		
Flight Depth, Inch (mm)	N.A.	0.625 (15.875)
No. of Flights		4
Transition Section	N.A.	
No. of Flights		1.5
Metering Section	N.A.	
Flight Depth, Inch (mm)		0.210 (5.334)
No. of Flights		4.5
Compression Ratio	N.A.	2.95:1

KRATON™ Polymers

[1] General Considerations
A. The screw pitch is equal to screw diameter.
B. The compression ratio equals depth of feed section / depth of the metering section.
C. If a vent is used with the two stage screw it should be at 16-17 flights from beginning of the screw feed.

With KRATON D Polymer compounds, die swell is less evident than with polyolefins. Die land length, therefore, is less critical. These polymer compounds often show some "set-up" if long flow paths are encountered after the melt leaves the shear field of the extruder screw. This "set-up," which can give surface roughness, arises from partial reformation of the physical crosslinks which develop among polymer endblocks as the melt moves to regions of low shear. Similar behavior may occur if die heating bands are far removed from the screw tip, because a long die adapter or melt piping is used.

Extrusion Conditions

Extrusion melt temperatures for KRATON D Polymer compounds should range from 300-390 °F (105-200 °C) and should not exceed 400 °F (205 °C). It is preferable to directly monitor this temperature near the die exit rather than relying on the temperature of the die head. The feed zone temperature should be no higher than 175 °F (80 °C). Increasing the zone temperatures along the extruder barrel from about 300 °F (148 °C) at the zone next to the feed zone, to about 390 °F at the die body, produces best outputs.

A reversed temperature profile can be used should excessive surging be encountered or should a very uniform melt be required. Alternatively, a choke bar or a finer, more restrictive screen pack can be used to increase back pressure. However, all of these measures may reduce output.

Because of midblock unsaturation in KRATON D Polymers, extrusion of these polymer compounds at high temperatures and / or high shear resulting from the use of high compression ratio screws (4:1) can give degradation, leading to gel formation and reduction in properties.

Coloring

KRATON D Polymer compounds can be colored during extrusion (See the discussion of coloring in the previous section on Injection Molding).

Post Extrusion

Take-off equipment used for handling conventional thermoplastics can also be used with KRATON D Polymer materials. When extruding film sheet, polish roll temperature should be about 150-175 °F (65-80 °C) to minimize roll sticking. Roll surface treatments similar to those discussed in the previous section on Mold Design can also be used to reduce sticking.

Because of the rubbery, flexible nature of many KRATON D Polymer extrudates, the effects of molecular orientation can be quite apparent. Since orientation is one result of draw-down, excessive draw-down should be avoided, particularly at lower extrusion temperatures.

Production Rates

Output of KRATON D Polymer compounds is generally greater than normally predicted from screw design. This is related to the high coefficient of friction against metal exhibited by these polymer compounds. For a given extruder size, the output of KRATON D Polymer compounds is almost linear with screw speeds. A 3.5" (900 mm) extruder, for example, can process 200 lbs / hr (90 kg / hr) at 30 rpm and about 500 lbs / hr (220 kg / hr) at 70 rpm.

Extrusion of KRATON G Polymer Compounds

With the advantages of improved thermal stability, resistance to shear degradation, and fast setting melts, KRATON G Polymer compounds are easy processing materials and, in this respect, can be superior to many engineering plastics and other thermoplastic rubbers. Many of the general recommendations for extruding KRATON D Polymer compounds given above also apply to KRATON G Polymer compounds. Some specific points are:

Screw and Die Design

Long extruders with L:D ratios of at least 24:1 are preferred; extruders with L:D ratios of less than 20:1 should not be used. Those with L:D ratios of 20:1 may require higher barrel temperatures to achieve a uniform melt temperature, and may need to be run at lower rpm.

KRATON G Polymer compounds extrude best with extruder screws having compression ratios of from 2.5:1 to 3.5:1, and long, rather shallow metering zones. Screws with short feed zones do not feed well. Balanced screws (i.e., those with equal number of flights in the feed, transition, and metering zones) of the type normally used to extrude polyolefins are preferred. Table 6 gives typical design ranges for single and two-stage screws for extruding KRATON G Polymer compounds.

Extrusion dies for use with KRATON G Polymer compounds should have minimum flow paths to prevent the development of surface roughness related to the "set-up" of these materials (See the corresponding section on KRATON D Polymer compounds). Long die adapters should be avoided, and both the die and die adapter should be provided with heaters.

Die land lengths need only be long enough to generate the required surface polish and product profile. Generally they should be less than 0.5" (12.7mm). While excessive draw-down should be avoided, some draw-down (about 10-20%) can result in improved extrudate strength.

Table 6:
Typical screw configuration for extrusion of KRATON™ G Polymer compounds

Characteristics[1]	Single Stage	Two Stage
Length / Diameter (L:D)	*24:1*	*24:1*
First Stage		
Feed Section		
Flight Depth, Inch (mm)	*0.490 (12.446)*	*0.500 (12.7)*
No. of Flights	*8*	*6*
Transition Section		
No. of Flights	*8*	*4*
Metering Section		
Flight Depth, Inch (mm)	*0.175 (4.445)*	*0.140 (3.556)*
No. of Flights	*8*	*4*
Compression Ratio	*2.8:1*	*2.5:1*
Second Stage		
Feed Section		
Flight Depth, Inch (mm)	*N.A.*	*0.625 (15.875)*
No. of Flights		*4*
Transition Section	*N.A.*	
No. of Flights		*1.5*
Metering Section	*N.A.*	
Flight Depth, Inch (mm)		*0.210 (5.334)*
No. of Flights		*4.5*
Compression Ratio	*N.A.*	*2.95:1*

KRATON™ Polymers

[1] General Considerations
A. The screw pitch is equal to screw diameter.
B. The compression ratio equals depth of feed section / depth of the metering section.
C. If a vent is used with the two stage screw it should be at 16-17 flights from beginning of the screw feed.

Extrusion Conditions

Melt temperatures during extrusion of KRATON G Polymer compounds are normally 375-450 °F (190-230 °C). However, because of the unique saturated elastomer midblock, temperatures of up to 500 °F (260 °C) are permissible. It is preferable to directly monitor the melt temperature near the die exit rather than relying on the temperature of the die head. The feed zone temperature should be no higher than 175 °F (80 °C). Increasing the zone temperatures along the extruder barrel from about 375 °F (190 °C) at the zone next to the feed zone, to about 455 °F (235 °C) at the die body, may be tried initially. This temperature profile may then be modified depending upon the KRATON G Polymer grade and extruder screw design.

Coloring

KRATON G Polymer compounds can also be colored during extrusion (Again, see the discussion of coloring in the previous section on Injection Molding).

Post Extrusion

The common take-off equipment in use for polypropylene or PVC extrusion is also suitable for KRATON G Polymer compounds. For sheet extrusion, chill and polish roll temperatures need to be held at about 140-180 °F (60-80 °C). Clean rolls and close control of roll temperature will minimize the roll sticking sometimes observed with the softer KRATON G Polymer compounds.

Profiles extruded from KRATON G Polymer compounds can be sized by drawing down. As with the KRATON D Polymer compounds, the physical properties can be modified somewhat by the degree of draw-down.

Production Rates

KRATON G Polymer compounds have nominal extrusion rates, comparable to those of other thermoplastics. The output rates tend to be lowest with the soft, rubbery grades, as represented by KRATON G7705 Polymer compound. Rates increase with products of intermediate hardness and stiffness, and are highest with the harder, filled grades as represented by KRATON G7820 Polymer compound.

Generally, the softer KRATON G Polymer compounds show a decrease of output with increasing back pressure. Frictional heating is lowest with soft grades and increases considerably with the hard grades.

Film and Monofilament Fiber Extrusion

Films and fibers can be produced from KRATON Polymer compounds specifically designed for this application. Extrusion blowing, extrusion casting, calendering, and melt spinning have all been used for this purpose. These KRATON Polymer compounds have very low modulus and tensile set. In this respect, they are superior to similar products made from such other flexible polymers as EVA, copolyesters, and thermoplastic polyurethanes.

For blown film extrusion, polyolefin type screws similar to those described in Table 6 are preferred. Die pressures are generally low. Melt temperatures should be about 325-375 °F (160-190 °C) for KRATON D Polymer compounds, and about 400-475 °F (205-245 °C) for KRATON G Polymer compounds. Die gaps of 0.025" to 0.030" (0.635 mm to 0.762 mm) can be used with blowup ratios up to 2:1. Film 2 mils thick can be produced under these conditions. A rollered collapsing frame is recommended because of the high coefficient of friction and softness of the product.

Insert Molding, Co-Injection Molding, and Co-Extrusion

All of these processes allow the production of parts with non-uniform characteristics. For example, they can be used to make multicolored items. More typically, they are used to make parts with both hard and soft regions. An example of insert molding is shown in Figures 9a-b. Here, a hard, stiff frame is first molded, then transferred to another mold and finally a softer surface is molded over it.

Adhesion between the different materials is obviously critical. In general, contact with plasticized PVC should be avoided. KRATON D Polymer compounds adhere well to each other and also to polystyrene and high impact polystyrene. Similarly, KRATON G Polymer compounds adhere well to each other and also to polyolefins such as polypropylene. If the above guidelines are followed, the mixed scrap can be reprocessed to provide a product of intermediate properties.

Injection molding over metal inserts is another application. In this case, adhesion to the metal can often be improved by dip coating it in a solution of a functionalized KRATON G Polymer.

Figure 9a:
Insert molding–
molding a stiff frame

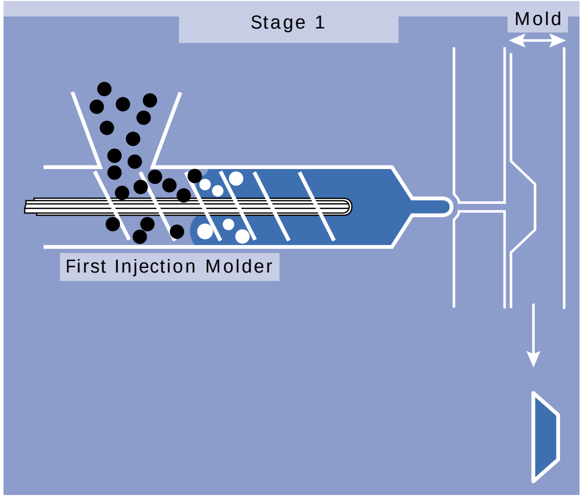

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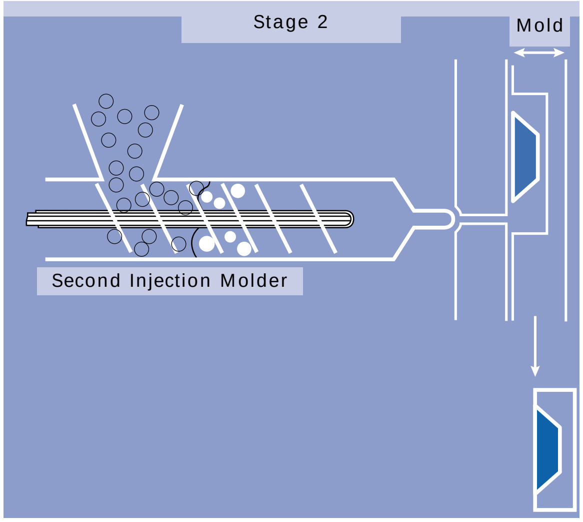
Figure 9b:
Insert molding–
overmolding a soft surface



KRATON™ Polymers

Blow Molding

KRATON Polymer compounds have been successfully formed into a variety of products by conventional blow molding techniques, including extrusion blow molding. Both the KRATON D and G Polymer compounds are readily adaptable to this process.

Machine Considerations

KRATON Polymer compounds have been successfully blow molded on various machines. The types which produce an intermittent fast drop parison are particularly well suited for use with these products, since this feature minimizes parison sag.

Optimum results are obtained with deep flighted, low compression ratio screws. This type of screw can allow a broader temperature range to be used without overheating or degrading the polymer.

Parison dimensions will vary with each of the KRATON Polymer grades, and also with the type of die. If fast extrusion rates are combined with a narrow die gap, higher swell will occur in the parison.

KRATON G Polymer compounds often benefit from the use of faster parison drop rates. Land length and geometry have a marked influence on die swell. Land lengths up to 12 times the die gap have been used, but while such long lands have a tendency to facilitate smoother parison surfaces and reduce swell, they are not necessary.

Molds

Conventional molds have performed well with KRATON Polymer compounds. Typical land widths are acceptable, with normal pinch-off configuration facilitating easy removal of excess parison.

The internal edges of the land may be very slightly rounded so that a sharp edge will not have a tendency to cause tearing of the molded article. The elastomeric nature of KRATON Polymer compounds allows the use of convex mold surfaces and undercuts. Molds with ample cooling channels are desirable to minimize cooling time.

Molding Conditions

Melt temperature should be in the range of 300-390 °F (150-200 °C) for KRATON D Polymer compounds, and 375-475 °F (190-245 °C) for KRATON G Polymer compounds. These temperatures will give good definition to the finished product. Lower temperatures may cause melt fracture; higher temperatures will lead to an undesirable parison sag, particularly if continuous parison type machines are used.

Within the indicated temperature range, blow ratios as high as 2.9:1 have been attained; however, a 2-2.5:1 blow ratio is more desirable.

Blowing pressures in the range of 35 to 120 psi (0.24 to 0.83 MPa) are required, depending upon the size of the object and the wall thickness. Because of the plasticity of these materials at normal processing temperatures, excessively high blow pressures are not required.

Thermoforming

KRATON D and G Polymer compounds can be used to mold many different articles by conventional thermoforming processes. The finished parts have sharp and well-defined details which can hold closely to the mold configuration (including undercuts), and possess good impact resistance, flexibility, and elasticity.

Forming Techniques

Extruded sheets made from KRATON D and G Polymer compounds can easily be formed into less complex shapes requiring relatively shallow draw-down by the use of simple vacuum or drape forming procedures. Deeper draws, however, require the use of a plug assist and / or billow forming for best results.

A plug assist pushes the heated sheet into the mold cavity before the vacuum is applied, and so gives more uniform wall thickness. An effective plug will assist the heated sheet in conforming to the size of the mold. The plug size, shape, and surface, as well as the depth of its penetration into the cavity, are all important factors in controlling the uniform distribution of material.

In addition to optimum plug size, sufficiently deep penetration into the mold minimizes thinning of the material on the lower wall and bottom corners. A reverse taper on the walls of the plug improves the uniformity and smoothness of the final part by making it easier for the heated sheet to roll around the corner of the plug as it penetrates the mold cavity. For the same reason, the bottom of the plug can be made from a low friction material such as Teflon™ (DuPont) or polypropylene.

Billow forming gives further improvements in wall thickness uniformity. In this technique, the heated sheet is first blown into a billow that has a thickness similar to that of the base of the product. This pre-stretches the sheet and allows the plug assist to more closely form the desired shape before the vacuum is applied.

Temperature Control

Optimum heating times vary widely, depending upon oven temperature, efficiency of the heating source, and thickness of the polymer sheet. For example, a .225" (5.715mm) sheet of a KRATON D Polymer compound was adequately heated in 70 seconds with a bottom oven temperature of about 400 °F (205 °C) and the top oven at 500 °F (260 °C). These temperatures would probably need to be increased somewhat to mold a similar sheet made from a KRATON G Polymer compound.

Shorter heating times may be obtained with a higher oven temperature; however, care must be taken not to exceed the temperature which causes excessive sag of the sheet to occur.

Injection Molding

Problem:	Possible Causes:	Possible Solutions:
Incomplete Fill	*Melt and / or mold too cold*	*1. Increase nozzle and barrel temperatures* *2. Increase mold temperature* *3. Increase injection rate* *4. Increase screw speed and back pressure*
	Heater(s) not working	*1. Check thermocouples and heater bands*
	Shot size	*1. Increase shot size* *2. Increase cushion*
	Mold design	*1. Check that gates are unplugged* *2. Enlarge gates* *3. Enlarge runners* *4. Check that vents are unplugged* *5. Enlarge vents* *6. Check location of vents* *7. Add vacuum assist to vents*
Sinks	*Hold pressure too low*	*1. Increase hold pressure*
	Melt and / or mold too hot	*1. Decrease nozzle and barrel temperatures* *2. Decrease mold temperature* *3. Decrease screw speed*
Burning	*Melt and / or mold too hot*	*1. Decrease nozzle and barrel temperatures* *2. Decrease mold temperature* *3. Decrease injection rate*
	Heater(s) stuck on	*1. Check thermocouples and temperature controllers*
	Mold design	*1. Enlarge vents* *2. Check that vents are unplugged* *3. Add vacuum assist to vents* *4. Check vent locations*
Odor or Yellowing	*Melt and / or mold too hot*	*1. Decrease nozzle and barrel temperatures* *2. Decrease mold temperature* *3. Decrease injection rate* *4. Decrease screw speed and back pressure* *5. Check temperature control of hot runners (if used)* *6. Bleed nitrogen into hopper*
Flashing	*Injection pressure too high*	*1. Decrease injection pressure* *2. Increase clamp pressure* *3. Decrease injection rate*
	Melt and / or mold too hot	*1. Decrease nozzle and barrel temperatures* *2. Decrease mold temperature* *3. Decrease screw speed*

Problem:	Possible Causes:	Possible Solutions:
Part Distortion	*Too much orientation*	*1. Increase mold and melt temperatures* *2. Decrease injection rate*
	Over-packing	*1. Decrease hold pressure* *2. Match injection time to mold fill time*
	Uneven mold fill	*1. Change gate locations* *2. Ensure uniform mold temperature* *3. Increase screw speed and back pressure*
Black Specks or Undispersed Lumps	*Contamination*	*1. Purge with low melt flow PP or HDPE* *2. Check that color concentrate is based on PS (for KRATON D), PP or PE (for KRATON G)* – NOT PVC
Sticking in Mold or Sprue	*Part is too hot*	*1. Decrease nozzle and barrel temperatures* *2. Decrease mold temperature* *3. Increase cooling time*
	Mold design	*1. Increase draft angles* *2. Use non-stick surface treatment*
Splaying at Gate	*Moisture*	*1. Dry pellets* *2. If using vented screw, check that vent is unplugged* *3. Add vacuum assist to vents*
Flow Lines	*Melt and / or mold too cold*	*1. Increase nozzle and barrel temperatures* *2. Increase mold temperature* *3. Increase injection rate* *4. Increase screw speed and back pressure*
	Mold design	*1. Change gate locations* *2. Enlarge gates* *3. Enlarge runners* *4. Add cold sinks to runners*
Voids	*Melt sets up too soon*	*1. Increase mold temperature* *2. Increase screw speed and back pressure*
	Moisture	*1. Dry pellets* *2. If using vented screw, check that vent is unplugged* *3. Add vacuum assist to vents*
	Hold pressure too low	*1. Increase hold pressure*

Extrusion

Problem:	Possible Causes:	Possible Solutions:
Rough Extrudate	*Melt too cold*	*1. Increase extruder temperature* *2. Increase die temperature*
	Heater(s) not working	*1. Check thermocouples and heater bands*
	Melt not mixed	*1. Use higher compression ratio screw or screw with mixing section*
	Poor die design	*1. Decrease land length*
Uneven Cross Section	*Surging*	*1. Decrease extrusion rate* *2. Use screw with longer feed or metering section* *3. Use more restrictive screen pack to increase back pressure* *4. Decrease die temperature*
Black Specks or Undispersed Lumps	*Contamination*	*1. Purge with low melt flow PP or HDPE* *2. Check that color concentrate is based on PS (for KRATON D), PP or PE (for KRATON G) – NOT PVC*
Odor or Yellowing	*Melt too hot*	*1. Decrease extruder barrel temperatures* *2. Decrease die temperature* *3. Decrease screw speed* *4. Use less restrictive screen pack to decrease back pressure* *5. Use lower compression ratio screw* *6. Bleed nitrogen into hopper*
	Heater(s) stuck on	*1. Check thermocouples and temperature controllers*
Voids	*Moisture*	*1. Dry pellets* *2. If using vented screw, check that vent is unplugged* *3. Add vacuum assist to vents*
High Extruder Pressure / Low Throughput	*Melt too cold*	*1. Increase extruder temperature* *2. Increase die temperature*
	Clogged screen pack	*1. Clean and / or replace*
	Heater(s) not working	*1. Check thermocouples and heater bands*

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