Celanese
The chemistry inside innovation™

Riteflex® TPC-ET

Thermoplastic polyester elastomer (TPC-ET)

Technical Manual

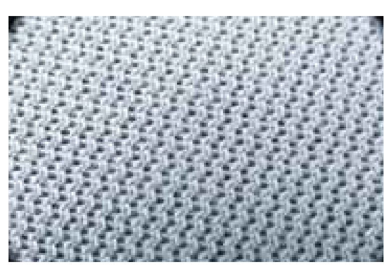
Table of Contents

Benefits of Riteflex® thermoplastic polyester elastomer (TPC-ET)

- Full Range of Shore D Hardness
- High Mechanical Strength
- Flexibility and Durability at Low Temperatures
- Chemical Resistance and Retention of Properties
- Tough and Resilient
- Superior Electrical Properties

Tank cap connector strip of Riteflex® 655

Monofilaments of Riteflex® TPC-ET



Upholstery fabric made from Riteflex® TPC-ET monofilaments

Overview 1
Properties 2
Processing 3
Part and Mold Design 4
Post-Processing 5

1. Overview

1.1 Product Description

Thermoplastic elastomers (TPC-ETs) are high-value materials capable of meeting performance requirements beyond the reach of many thermoset rubbers, especially in thermal, oxidative and chemical resistance. They provide a controllable combination of hard and soft segments to offer many of the desirable properties of thermoset elastomers while still providing the processing ease, recyclability and regrind, re-use capability of thermoplastics.

Riteflex® thermoplastic polyester elastomer (TPC-ET) resins are random copolymer TPC-ETs that combine toughness and resilience with excellent resistance to creep, impact, tearing and flexural fatigue. They perform over a wide temperature range from -40°C to 121°C (-40°F to 250°F), have good impact at low temperatures, yet retain functionality at high temperatures. They have excellent chemical resistance to common solvents, oils and greases and dilute acids and bases. These desirable properties of Riteflex TPC-ET are founded on their chemical relationship to the other members of Celanese's polyester family, with hard segments generally based on polybutylene terephthalate (PBT), the base resin for Celanex® PBT products.

Riteflex thermoplastic polyester elastomers are available as unreinforced polymers in a wide range of Shore D hardnesses. In general, the harder versions have enhanced heat and chemical resistance, while the softer materials possess good low-temperature mechanical properties. The range of properties available from Riteflex TPCET is reflected in the diversity of applications for these versatile materials: hose, tubing, seals, gaskets, belts, pump diaphragms, wire coatings, hooks, fasteners, film, sheet, nonwovens and monofilaments, to name some of the more outstanding. A properly chosen Riteflex resin grade allows replacement of a multipiece plastic or rubber component by a single part in many applications. Specialty Riteflex TPC-ET products are also available, such as heat-stabilized or UV-stabilized grades. These resins may also be compounded with fillers and/or reinforcements such as fiberglass. Colored formulations can be provided as required for particular applications.

Conventional thermoplastics processing methods, particularly injection molding and extrusion, may be used with Riteflex TPC-ET materials. Processing temperatures range between 310° and 500°F (155° and 260°C), depending on the specific process and the grade chosen. The PBT-based hard segments provide these materials with sharp melting points, and they are designed to have good melt stability, assuring ready processability. Twoshot injection molding of Riteflex resins for overmolding or to make a unified part containing both hard and soft components is a particularly useful technique. The range of properties available with Riteflex resins gives designers new options. Part design methods for Riteflex TPC-ET are generally similar to approaches used with other engineering resins, including the use of standard design equations. In these equations, the lower yield stress of elastomer materials should be taken into consideration. As with all plastic materials, testing in the end-use, particularly at extreme conditions, is an essential element in material and part qualification. The appropriate Material Safety Data Sheet (MSDS) should be consulted before processing any Riteflex resin.

1.1.1 Crystallinity

The PBT-based hard segments in the various grades of Riteflex TPC-ET can contain both crystalline and amorphous regions. The longer the hard segment, the more likely it will have regions of crystallinity. Accordingly, harder grades of Riteflex TPC-ET manifest a higher degree of crystallinity than softer grades and exhibit a sharper crystalline melting point.

1.2 Available Grades

Celanese offers Riteflex TPC-ET resins covering a broad range of Shore D hardnesses, from D25 to D77. Special grades, such as custom colors, special-effect appearance (i.e., MetaLX™), heat-stabilized, UV-stabilized, laser markable and non-halogenated flame-retardant grades can be provided for specific applications.

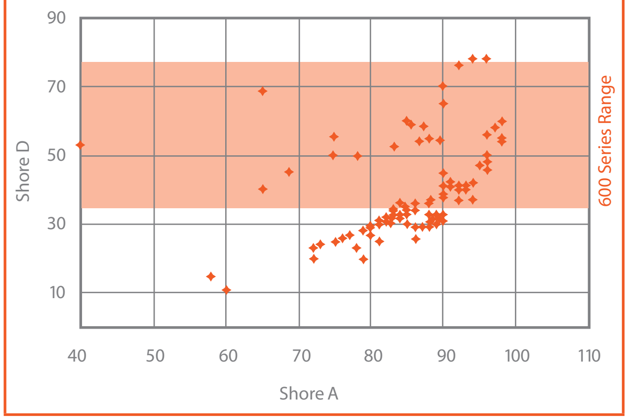
The hardness of plastics is most commonly measured by the Shore (Durometer) test or by the Rockwell test. Both methods yield a useful empirical value that, however, is not a good predictor of other properties such as strength or resistance to scratches, abrasion or wear. It should not be used alone for product specifications. Measurement is by means of a Durometer apparatus, which determines the penetration of the indenter foot into the sample. Because of the resilience of rubbers and plastics, the indentation reading may change over time, so the indentation time is sometimes reported along with the hardness number. Shore Hardness is the preferred method for rubbers/elastomers and is also commonly used for "softer" plastics such as polyolefins, fluoropolymers and vinyls. The Shore A scale is used for "softer" rubbers while the Shore D scale is used for "harder" ones.

As shown in Figure 1.1, the correlation between the two Shore Durometer hardness scales for a range of materials is weak and conversion between them is variable. Although the correlation is better for materials with similar resiliency properties, it is still not adequate for reliable conversions. The situation is similar for conversions between the Shore and Rockwell scales.

The Riteflex® TPC-ET 600 series encompasses Shore D hardness ratings from 40 to 77. For the five grades in this 600 series, the last two digits in the grade identifier indicate the Shore D hardness. In general, within the 600 series range, density, stiffness and strength increase with increasing hardness, while moisture absorption, elongation and impact resistance decrease.

The Riteflex TPC-ET 400 series products provide soft polyester elastomer materials with good high temperature capability. These grades offer outstanding flexibility and flex fatigue resistance at lower temperatures, as well as having low moduli at room temperature and above. The 400 series includes Riteflex

Fig.1.1 • Comparison of Shore Hardness Scales, Showing Riteflex COPE 600 Series Range



grades 425, 435, 440 and 447. As with the 600 series, the last two digits in the grade identifier indicate the Shore D hardness for that grade.

Table 1.1 lists the standard grades of Riteflex TPC-ET together with brief descriptions of each grade. Should it be necessary to tailor the properties of a standard grade to meet the requirements of a specific application, such as for instance incorporating a heat stabilizer package or matching a color, Celanese engineers can, where appropriate, make a special product to satisfy the needs of the applica-

Table 1.1 • Standard Grades of Riteflex® TPC-ET

Grade	Description	Applications
425	Extrusion/Injection grade; Shore D hardness 25, low modulus molding and extrusion, outstanding temperature impact, tear resistance	Film extrusion, films, injection molded soft touch grips, non-slip surfaces
435	Extrusion/Injection grade; Shore D hardness 35, low modulus molding and extrusion, low temperature impact strength, tear resistance	Film, wire and cable jackets, non-slip, various hose and tubing, pump diaphragms, non-slip mats, cell phone/pager buttons and keypads, profiles
440	Extrusion/Injection grade; nominal Shore D hardness 40, medium modulus, molded and extrusion grade	Film, monofilaments, wire and cable jackets, profiles, injection molded products, hose and sprinkler seals, profiles and grommets
447	Extrusion/Injection grade; nominal Shore D hardness 47, medium modulus, molded and extrusion grade	Coin trays, cup holders, shifter boots and knobs, various hose and tubing, prop shaft boots, belting, profiles, cable jacketing
640A	Extrusion/Injection grade; Shore D hardness 40, medium modulus; low melt temperature and higher modulus vs. 440	Film, monofilaments, wire and cable jackets, profiles, injection molded products, hose and sprinkler seals, profiles and grommets
655A	Extrusion/Injection grade; Shore D hardness 55, medium modulus, molded and extrusion grade	Grommets, bumper pads and body plugs, low noise gears, belting, profiles, wire and cable jacket
663	Extrusion/Injection grade; Shore D hardness 63, medium modulus, molded and extrusion grade	Grommets, body plugs, A/C louver, connectors, seals, bushings and profiles
672	Extrusion/Injection grade; nominal Shore D hardness 72, high modulus, molded and extrusion grade	Gears, sprockets, electrical connectors, profiles, seals and bushings
677	Extrusion/Injection grade; nominal Shore D hardness 77, high modulus, molded and extrusion grade	Connectors, gears and sprockets, electrical connector and bushings

1.3 Regulatory Compliance

Riteflex® TPC-ET resins are in compliance with or have ratings under the standards of many regulatory codes and agencies including:

- American Society for Testing and Materials (ASTM)
- Underwriters Laboratories (UL)
- United States Food and Drug Administration (FDA)

1.3.1 UL

Table 1.2 • UL Ratings
(50°C is the Generic UL Temperature Rating for TPC-ETs)

				Relative Temperature Index (RTI),°C		
	Color	Min. Thick., mm	UL94	Electrical	Mech. w/ impact	Mech. w/o impact
425	ALL	1.50	HB	50	50	50
640A	ALL	1.50	HB	50	50	50
655A	NC, BK	1.50	HB	50	50	50
663	NC, BK	1.50	HB	50	50	50
672	NC, BK	1.50	HB	50	50	50
677	NC, BK	1.50	HB	50	50	50

NC = Natural color, BK = Black, ALL = All colors

1.3.2 FDA – Food Contact Compliance

Riteflex 400 and 600 series are FDA/EU food contact compliant for repeat use only, except single use for bulk dry food with no surface fat or oil. Please contact your local account representative when approvals are required.

1.4 Product Support

Celanese provides its customers with comprehensive product support, including:

- Application assessment
- Part analysis
- Product recommendations
- Specification development and qualification
- Color matching services
- Product technical data
- Part design advice
- Processing recommendations
- On-site processing assistance
- Safety and health advice
- Quality process assistance

For information and assistance, please contact your Celanese representative or call Celanese Product Information Services at 1-800-833-4882.

1.5 Design Support

The technical expertise available from Celanese's engineering staff is backed up by the most modern computer technology for part design and processing. Stress and strain data under various scenarios are provided by finite element analyses and processing variables are modeled. Input data for these programs are also available to our customers if they wish to run their own analyses.

Please contact your Celanese representative to arrange for these services.

1.6 General Safety and Health

Standard precautions when working with hot molten plastics must be observed when processing Riteflex® thermoplastic polyester elastomers. Before handling or processing any Riteflex TPC-ET grade, please obtain and read the appropriate Material Safety Data Sheet (MSDS) for detailed safety, health and environmental information. Use process controls, work practices and protective measures as described in the MSDA to control workplace exposure to dust and volatiles.

MSDS documentation can be obtained by contacting your Celanese representative, from Celanese Customer Service 1-800-833-4882 or on the Celanese web site http://tools.ticona.com/tools/restricted/mbase/mcbasei/ msds.php.

1.7 Reference Publications

More information on plastics and on Riteflex products is available on Celanese's web site www.Celanese.com.

2. Properties

The Riteflex® TPC-ET product line covers an extended range of Shore D hardness values. Though related in chemical composition, the various Riteflex TPC-ET products consequently offer a wide range of physical, mechanical and other properties as shown in the following tables.

Table 2.1 • Physical Properties

			Riteflex® Thermoplastic Polyester Elastomers										
	Method	**Units**	**425**	**435**	**440**	**447**	**640A**	**655A**	**663**	**672**	**677**	**XFR 440**	**XFR 655**
Density	ISO 1183	g/cm^3	1.06	1.10	1.11	1.15	1.13	1.19	1.24	1.26	1.27	1.20	1.23
Melt flow rate, 2.16kg load (°C)	ISO 1133	g/10 min	13 (190)	9 (220)	13 (220)	15 (240)	10 (220)	10 (220)	19 (240)	16 (240)	15 (240)	16 (250)	25 (250)
Water absorption, immersion, 24 hr.	ISO 62	%	0.6	0.6	0.5	0.4	0.5	0.4	0.3	0.2	0.2	—	—
Water absorption, immersion, saturation	ISO 62	%	0.6	0.6	0.5	0.6	0.5	0.4	0.4	0.3	0.3	—	—
Moisture absorption (23°C, saturation)	ISO 62	%	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	—	—
Mold shrinkage, flow, 60 x 60 x 2 mm	ISO 294	%	1.2	1.3	1.2-1.4	1.3-1.8	1.2-1.4	1.6-1.9	1.7-2.0	1.7-2.2	1.8-2.2	—	—
Mold shrinkage, transverse, 60 x 60 x 2 mm	ISO 294	%	0.9	1.0	1.2	1.5	1.0	1.3	1.6	1.4	1.2	—	—

Deep-draw liners and containers of Riteflex TPC-ET

2.1 Benefits of Additives

Properties of Riteflex TPC-ET can be enhanced by the addition of performance modifiers.

Table 2.2 Heat Stabilized Riteflex 655HS vs. 655A – Property Retention After Long-Term Thermal Exposure (145°C Oven Aging)

Property	ASTM Test	655A	655HS
After 168-Hour Exposure			
Tensile strength	D638	82%	98%
Tensile elongation	D638	10%	95%
After 504-Hour Exposure			
Tensile strength	D638	19%	88%
Tensile elongation	D638	1%	31%
After 840-Hour Exposure			

Table 2.3 • Mechanical Properties

			Riteflex® Thermoplastic Polyester Elastomers										
	Method	Units	425	435	440	447	640A	655A	663	672	677	XFR 440	XFR 655
Tensile stress at yield (50 mm/min)	ISO 527	MPa	No Yield	No Yield	No Yield	No Yield	No Yield	15	21	28	33	—	—
Tensile strain at yield (50 mm/min)	ISO 527	%	No Yield	No Yield	No Yield	No Yield	No Yield	28	22	19	18	—	—
Nominal strain at break (50 mm/min)	ISO 527	%	>500	>500	>500	>500	>500	>500	>450	>300	>300	>500	>500
Stress at 5% strain	ISO 527	MPa	1	2	2	—	3	8	13	21	32	—	—
Strain at 10% strain	ISO 527	MPa	2	3	4	—	5	12	18	27	36	—	—
Stress at 50% strain	ISO 527	MPa	3	6	7	—	8	15	19	25	26	—	14
Stress at break	ISO 527	MPa	10	16	18	25	17	30	38	40	42	10	16
Elongation at break	ISO 527	%	NB*	NB*	NB*	—	550	520	455	300	300	—	—
Tensile modulus	ISO 527	MPa	16	45	55	95	65	175	350	500	750	100	360
Tensile stress at yield (50 mm/min), 1BA bar	ISO 527	MPa	No Yield	No Yield	No Yield	No Yield	No Yield	No Yield	20	26	33	—	—
Tensile strain at yield (50 mm/min),1BA bar	ISO 527	%	No Yield	No Yield	No Yield	No Yield	No Yield	No Yield	23	17	11	—	—
Flex modulus, -40°C	ISO 178	MPa	162	240	270	—	115	700	1900	2400	2500	—	—
Flex modulus, 23°C	ISO 178	MPa	17	35	45	90	70	175	325	450	650	—	—
Flex modulus, 100°C	ISO 178	MPa	8	19	26	—	32	86	150	210	240	—	—
Flex strength	ISO 178	MPa	1	3	4	6	5	10	17.5	22	30	—	—
Charpy impact strength, 23°C	ISO 179	kJ/m^2	NB	NB	NB	NB	NB	NB	NB	NB	NB	—	—
Charpy impact strength, -30°C	ISO 179	kJ/m^2	NB	NB	NB	NB	NB	NB	NB	NB	71	—	—
Charpy notched impact strength, 23°C	ISO 179	kJ/m^2	NB	NB	NB	NB	NB	150p	105p	19c	9.4	25	13
Charpy notched impact strength, -30°C	ISO 179	kJ/m^2	NB	NB	NB	45p	NB	65p	22	4.5c	4.5c	—	—
Izod notched impact strength, -40°C	ISO 180	kJ/m^2	NB	NB	NB	NB	NB	NB	7c	4.8c	4.7c	—	—
Izod notched impact strength, 23°C	ISO 180	kJ/m^2	NB	NB	NB	NB	NB	NB	74p	16c	8.5	—	—
Initial tear resistance, Die C, normal	ISO 34	kN/m	62	89	92	—	75	116	150	186	237	—	—
Initial tear resistance, Die C, parallel	ISO 34	kN/m	61	89	96	—	84	124	160	193	250	—	—
Hardness, Durometer D (maximum)	ISO 868		24	35	38	45	40	55	63	70	75	40	55

*Break strain exceeds the limit of the crosshead motion of the test instrument (Approximately 550%) P = Partial C = Complete NB = No Break

Table 2.4 • Thermal Properties

			Riteflex® Thermoplastic Polyester Elastomers										
	Method	**Units**	**425**	**435**	**440**	**447**	**640A**	**655A**	**663**	**672**	**677**	**XFR 440**	**XFR 655**
Melting temperature, 10°C/min	ISO 11357	°C	155	185	195	212	170	200	212	215	218	195	200
Glass transition temperature, DMA	ASTM D5026	°C	-47	-45	-41	—	-41	-18	14	34	62	—	—
Heat deflection temperature, 0.45MPa	ISO 75	°C	42	45	47	60	56	75	114	118	129	—	—
Heat deflection temperature, 1.8MPa	ISO 75	°C	NT*	NT*	NT*	NT*	NT*	45	51	54	51	—	—
Coefficient of linear thermal expansion, 23°C - 80°C (longitudinal)	ISO 11359/ DIN 53 752	K-1	0.00025	0.00024	0.00024	0.00022	0.00022	0.0002	0.00018	0.00014	0.00014	—	—
Vicat softening temperature, 10N, 50°C/hr	ISO 306	°C	61	122	127	—	119	176(A)	194	205	213	—	—
Flammability, UL rating @ 1.5 mm	UL 94		HB	HB	HB	HB	HB	HB	HB	HB	HB	V-0	V-0

*The moduli of these materials are too low to allow for meaningful results.

Table 2.5 • Electrical Properties

			Riteflex Thermoplastic Polyester Elastomers										
	Method	**Units**	**425**	**435**	**440**	**447**	**640A**	**655A**	**663**	**672**	**677**	**XFR 440**	**XFR 655**
Relative permittivity* @ 1MHz	IEC 60993		5.1	5.1	4.9	4.7	4.7	4.4	4.0	3.7	3.3	—	—
Dissipation factor at 1MHz	IEC 60250		0.01	0.02	0.02	0.05	0.03	0.04	0.04	0.04	0.02	—	—
Dielectric strength P25/P75	IEC 60243	kV/mm	23.5	25	25.5	13	13	14	14	28.4	16	14	15
Comparative tracking index (CTI)	IEC 60122	V	>600	>600	>600	>600	>600	>600	>600	>600	>600	>600	>600
Volume resistivity	IEC 60092	ohm*cm	$3x10^{11}$	$2x10^{11}$	$2x10^{11}$	$4x10^{12}$	$5x10^{12}$	$4x10^{12}$	$2x10^{13}$	$2x10^{13}$	$3x10^{14}$	—	—
Surface resistivity	IEC 60093	ohm*cm	$2x10^{14}$	$2x10^{15}$	$2x10^{15}$	$2x10^{15}$	$3x10^{15}$	$4x10^{15}$	$1x10^{16}$	$2x10^{17}$	$2x10^{17}$	—	—

*AKA dielectric constant.

2.2 Stress Relaxation vs. Temperature

Contact your local Celanese representative for technical information.

Both cast film and sheet stock can be prepared from Riteflex® TPC-ET. In general, care should be exercised in production of films from grades with Shore hardness below about 40 D. The use of release sheets, slip and/or release agents may be necessary with these softer grades to facilitate processing.

Table 2.6 • Film Properties

			Riteflex Thermoplastic Polyester Elastomers	
	Method	Units	663	677
CAST Monolayer Film, 35mµ thick test specimens CAST AT:			**100°F (200°F)***	**100°F (200°F)***
Tensile strength @ break, machine direction (MD)	ASTM D882	psi	8,569 (9,207)	8,977 (10,096)
Tensile strength @ break, transverse direction (TD)	ASTM D882	psi	7,194 (7,253)	8,402 (10,631)
Elongation @ break , MD	ASTM D882	%	940.75 (924.16)	837.88 (845.02)
Elongation @ break, TD	ASTM D882	%	865.40 (840.02)	811.00 (826.83)
Tensile strength @ yield, MD	ASTM D882	psi	3,234 (2,819)	5,577 (5,285)
Tensile strength @ yield, TD	ASTM D882	psi	2,999 (2,525)	5,340 (5,312)
Elongation @ yield, MD	ASTM D882	%	25.41 (21.27)	7.48 (4.76)
Elongation @ yield, TD	ASTM D882	%	18.48 (16.58)	7.26 (5.22)
Dart drop impact strength, F50	ASTM 1709A	g	317.0 (290.0)	86.3 (69.9)
Elmendorf tear strength, MD	ASTM 1922	g	130 (392)	51 (78)
Elmendorf tear strength, TD	ASTM 1922	g	162 (251)	54 (85)
Gloss, 60°	ASTM D523		23.3 (50.0)	48.3 (75.0)
Haze	ASTM D1003 mod.	%	91.45 (0.30)	15.73 (0.35)
Yellowness Index	ASTM D1925		5.72 (1.20)	8.78 (1.15)
Oxygen permeability, 23°C, 0% RH	Internal Method	cm^3 / $100in^2$ day atm	68.4 (63.0)	N/M
Oxygen permeability, 23°C, 50% RH	Internal Method	cm^3/ $100in^2$ day atm	68.4 (64.0)	N/M
Oxygen permeability, 23°C, 100% RH	Internal Method	cm^3/ $100in^2$ day atm	71.7 (65.9)	N/M
Water Vapor Transmission Rate, 38°C		g / m^2 day	338.5 (301)	
CAST Monolayer Film, 70mµ thick test specimens CAST AT:AST M				
Tensile strength @ break, machine direction (MD)	ASTM D882	psi	7,261 (7,474)	9,854 (10,663)
Tensile strength @ break, transverse direction (TD)	ASTM D882	psi	7,503 (8,161)	9,282 (11,241)
Elongation @ break , MD	ASTM D882	%	940.66 (940.70)	905.31 (902.07)
Elongation @ break, TD	ASTM D882	%	941.18 (920.45)	865.97 (858.00)
Tensile strength @ yield, MD	ASTM D882	psi	3,032 (2,450)	5,597 (5,354)
Tensile strength @ yield, TD	ASTM D882	psi	2,954 (2,476)	5,604 (5,402)
Elongation @ yield, MD	ASTM D882	%	26.37 (21.83)	8.50 (5.54)
Elongation @ yield, TD	ASTM D882	%	23.95 (18.58)	7.57 (5.20)
Dart drop impact strength, F50	ASTM 1709A	g	474.5 (879.5)	266.0 (194.0)
Elmendorf tear strength, MD	ASTM 1922	g	149 (384)	99 (182)
Elmendorf tear strength, TD	ASTM 1922	g	149 (288)	112 (160)
Gloss 60°	ASTM D523		23.3 (78.3)	56.7 (160.0)
Haze	ASTM D1003 mod.	%	99.30 (0.96)	41.52 (0.41)
Yellowness Index	ASTM D1925		10.55 (2.08)	14.49 (1.55)
Oxygen permeability, 23°C, 0% RH	Internal Method	cm^3/ $100in^2$ day atm	34.1 (29.9)	N/M
Oxygen permeability, 23°C, 50% RH	Internal Method	cm^3/ $100in^2$ day atm	34.9 (31.7)	N/M
Oxygen permeability, 23°C , 100% RH	Internal Method	cm^3/ $100in^2$ day atm	36.6 (32.7)	N/M
Water Vapor Transmission Rate, 38°C		g/m^2day	222 (93)	

*Casting Roll Temperature
Contact your local Celanese development engineer for data.

2

2.3 Chemical Resistance

The chemical resistance of a polymeric material depends on the chemical and polymer in question. Temperatures and the exposure times play an important role, as well as the possible involvement of other factors such as ultraviolet or other high-energy radiation. Some reagents are absorbed and swell the polymer, while others may dissolve it or cause embrittlement or even decomposition.

Riteflex® thermoplastic polyester elastomers vary in composition; different grades may respond differently to the same chemical environment. Table below provides chemical resistance ratings for various Riteflex TPC-ET materials based on actual testing but also on a general knowledge of how the chemicals affect other polyester materials. Where the rating pertains to a grade of a specific Shore D hardness, the hardness value is included in parentheses. The ratings are as follows:

E: No adverse reaction, little or no absorption, little or no effect on mechanical properties

G: Some effect, some absorption with slight swelling and eduction in mechanical properties

W: No data. Available information suggests little absorption or effect on mechanical properties

NR: Not recommended, material adversely affected in a short time

Table 2.7 • Chemical Resistance

Chemical	Rating
Acetic Acid 20-30%	E
Acetic Acid, Glacial	E
Acetic Anhydride	W
Acetone	G
Acetylene	E
Aluminum Chloride Solutions	W
Aluminum Sulfate Solutions	W
Ammonium Hydroxide	W
Aniline	NR
Asphalt	W
ASTM Oil No. 1 (149°C)	E
ASTM Oil No. 3 (149°C)	E
ASTM Reference Fuel A	E
ASTM Reference Fuel B (70°C)	E
ASTM Reference Fuel C	E
ASTM Reference Fuel C (70°C)	G (40,55)
ASTM Reference Fuel C (70°C)	E (77)

Table 2.7 • Chemical Resistance

Chemical	Rating
Barium Hydroxide Solutions	W
Beer	E
Benzene	G (40,55)
Benzene	E (77)
Bromine, Anhydrous Liquid	NR
Butane	E
Butyl Acetate	G (40,55)
Butyl Acetate	E (77)
Calcium Chloride Solutions	E
Calcium Hydroxide Solutions	W
Carbon Dioxide	E
Carbon Monoxide	E
Carbon Tetrachloride	NR (40)
Carbon Tetrachloride	G (55)
Carbon Tetrachloride	E (77)
Chlorine Gas, Wet & Dry	NR
Chloroacetic Acid	NR
Chlorobenzene	NR
Chloroform	NR (40,55)
Chloroform	G (77)
Chlorosulfonic Acid	NR
Citric Acid Solutions	E
Copper Chloride Solutions	E
Copper Sulfate Solutions	E
Cyclohexane	E
Dibutyl Phthalate	E
Diethyl Sebacate	E
Dioctyl Phthalate	E
Epichlorohydrin	NR
Ethanol	E
Ethyl Acetate	G (40,55)
Ethyl Acetate	E (77)
Ethyl Chloride	NR (40,55)
Ethyl Chloride	G (77)
Ethylene Dichloride	NR (40,55)
Ethylene Dichloride	G (77)
Ethylene Glycol	E
Ethylene Oxide	E
Ferric Chloride Solutions	G
Formaldehyde 40%	G
Formic Acid (dilute)	G
Freon 11, 12, 114	E

Table 2.7 • Chemical Resistance

Chemical	Rating
Freon 113 (54°C)	E
Gasoline	E
Glycerin	E
n-Hexane	E
Hydrochloric Acid 20%	G
Hydrochloric Acid 37%	NR
Hydrofluoric Acid 48%, 75%	NR
Hydrofluoric Acid Anhydrous	NR
Hydrogen	E
Isooctane	E
Isopropanol	E
JP-4 Jet Fuel	E
Kerosene	G
Lacquer Solvents	G (40,55)
Lacquer Solvents	E (77)
Linseed Oil	NR
Magnesium Chloride Solutions	NR
Magnesium Hydroxide Solutions	NR
Methanol	E
Methyl Ethyl Ketone	G (40,55)
Methyl Ethyl Ketone	E (77)
Methylene Chloride	NR
Mineral Oil	E
Naphtha	E
Naphthalene	G (40,55)
Naphthalene	E (77)
Nitric Acid 10%	G
Nitric Acid 30%-70%	NR
Nitric Acid, Red Fuming*	NR
Nitrobenzene	NR
Oleic Acid	E
Oleum 20%-25%	NR
Palmitic Acid	E
Perchloroethylene	NR (40,55)
Perchloroethylene	E (77)
Phenol	NR

Table 2.7 • Chemical Resistance

Chemical	Rating
Pickling Soln. (20% HNO_3 4%HF)	NR
Potassium Dichromate Solutions	W
Potassium Hydroxide Solutions (dilute)	E
Pyridine	NR
SAE 10 Oil	E
Sea Water	E
Silicone Grease	E
Skydrol 500B	E
Soap Solutions	E
Sodium Chloride Solutions	E
Sodium Dichromate 20%	W
Sodium Hydroxide 20%	E
Sodium Hydroxide 46%	W
Stannous Chloride 15%	W
Steam (100°C)	W
Steam (110°C)	NR
Stearic Acid	W
Sulfur Dioxide, Gas	W
Sulfur Dioxide, Liquid	W
Sulfuric Acid, 50%	NR
Sulfurous Acid	G
Tannic Acid 10%	E
Tetrahydrofuran	G (40,55)
Tetrahydrofuran	E (77)
Toluene	G (40,55)
Toluene	E (77)
Trichloroethylene	NR (40,55)
Trichloroethylene	G (77)
Triethanolamine	NR
Trisodium Phosphate Solution	E
Tung Oil	G
Water (70°C)	G
Water (100°C)	W
Xylene	G (40,55)
Xylene	E (77)
Zinc Chloride Solutions	E

3. Processing

3.1 General

Riteflex® thermoplastic polyester elastomers are most commonly processed by injection molding and extrusion. Processing conditions are typically determined by the melting point of the grade being processed. General processing and handling procedures are similar to those appropriate for other thermoplastic polyesters.

3.1.1 Resin Storage

Store resins properly to help prevent damage to packaging and possible subsequent contamination. During storage, care should be taken to avoid extremes of temperature and humidity, which could lead to excessive moisture condensation and/or surface adsorption. These precautions are particularly important with regard to open containers of resin and for reground material intended for re-use, as the large surface area of regrind can facilitate moisture pickup. In any case, both virgin and reground materials must be dried to the recommended moisture levels before processing begins.

3.1.2 Recycling Scrap

Properly dried polyester materials have excellent thermal stability during melt processing. This enables use of up to 25% regrind subject to the requirements that it be free of contamination and properly dried together with the virgin resin before processing.

3.1.3 Ventilation

The process area should be adequately ventilated in general. An exhaust vent should be located over the molding machine or extruder to remove any gas or dust. Vented air quality should be in compliance with any applicable regulations.

3.1.4 Startup and Shutdown

Before feeding Riteflex resin to the equipment, the machine should be adequately purged to remove any other type of plastic previously run on it. Suitable purge materials include polyethylene, polypropylene and polystyrene. For parts intended for subsequent painting, adhesively bonded or printed, a final purge with a low molecular weight PBT such as Celanex® PBT grade 1400 may be used to clear residual olefin resin from the machine. Temperatures should then be adjusted to the appropriate settings for the Riteflex resin grade that is to be run.

When a machine is being shut down from processing Riteflex resin, the barrel and nozzle or die heaters should be maintained at their processing setpoints and the machine purged with polyethylene or polypropylene. The machine may then be shut down when no more Riteflex polymer issues from the nozzle or die.

3.1.5 Changing Feedstocks

To change from one grade of Riteflex thermoplastic polyester elastomers to another, machine settings should be adjusted to the proper levels for the new grade and the process run for a sufficient time for the melt inventory to be converted to the new material. If the new material is another thermoplastic polyester resin such as, for instance, Celanex PBT, the changeover may be carried out in the same way. If the change is to a different resin, the machine should be properly purged as previously described before introduction of the new material.

3.2 The Molding Process

As with all thermoplastic polyester materials, careful process control is essential to produce consistent high quality parts. Part quality and performance depends as much on proper processing as it does on part design.

3.2.1 Plastication

In this first stage of processing, the dried resin is fed from the hopper into the machine barrel, where it is melted by heat transfer from the barrel and shear energy generated in the screw transition zone. The molten resin is then pressurized and conveyed through the metering zone to form a melt pool in front of the screw. As the melt pool accumulates a sufficient volume for the injection shot, it forces the screw to retract in preparation for injection.

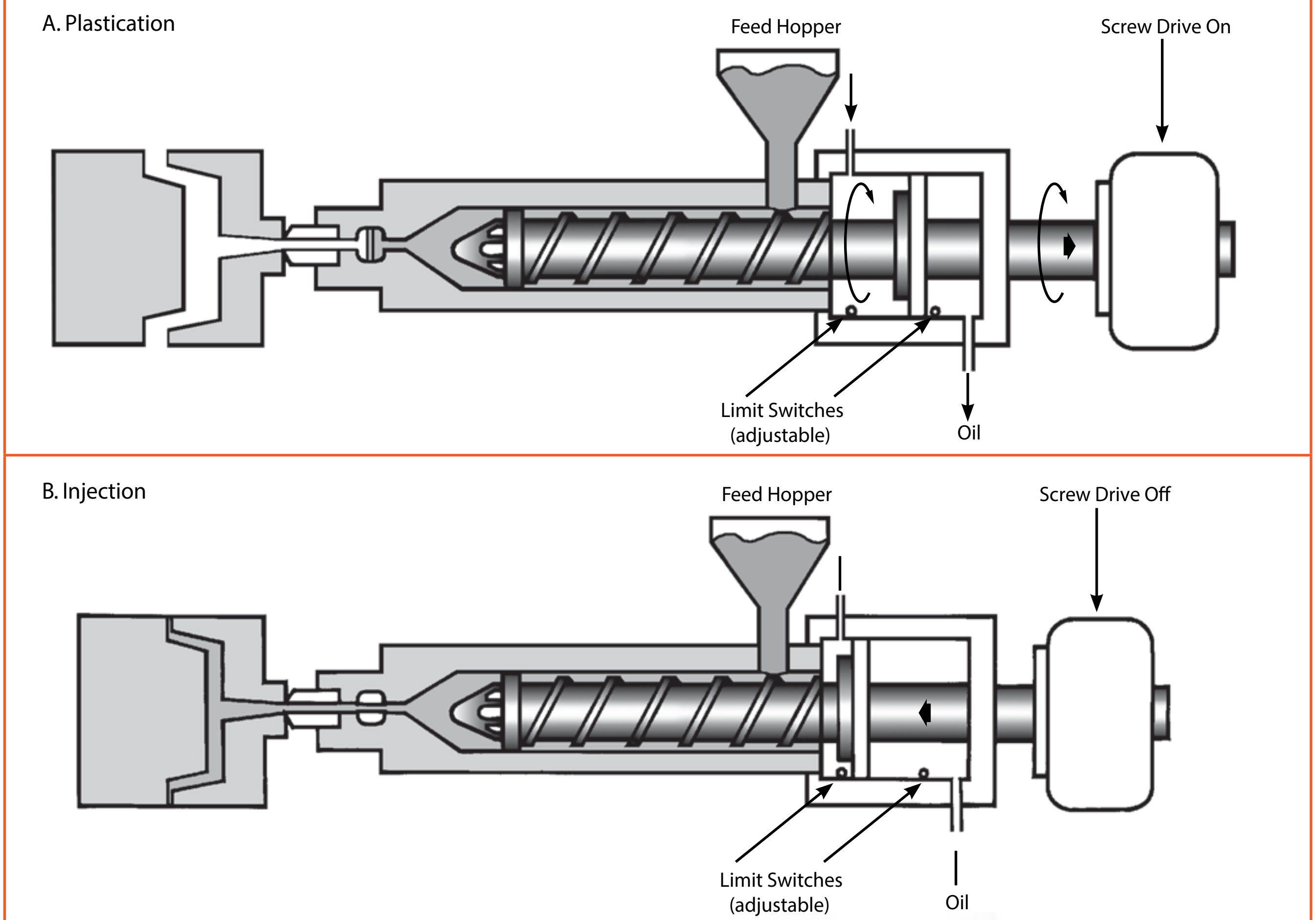
3.2.2 Injection

Screw rotation ceases and the screw is driven forward, seating the check ring at its forward end. This forces the polymer melt through the sprue and runner system of the mold to then pass through the cavity gate(s) and fill the mold cavity. The injected material solidifies in the cooled mold, from which it is ejected (usually by ejector pins) when the mold opens.

3.3 Molding Equipment

As shown in Figure 3.1, a typical reciprocating screw injection molding machine (often called a press in former times) consists primarily of a barrel with a screw inside it. The barrel temperature is controlled by external heaters and the screw may be both rotated and moved backward and forward. A feed hopper is located on an aperture in the top rear of the barrel. The mold, also called a tool or die, is attached to the front end of the barrel. Ancillary equipment such as mold heating/cooling apparatus is externally connected to the machine.

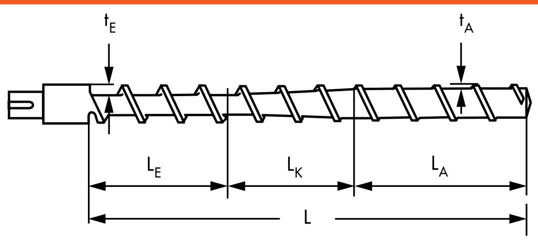
Fig. 3.1 • Molding Sequence, Single-Stage Reciprocating Screw Injection Molding Machine



3.3.1 Screw Design

A three-stage screw is commonly employed to process resins having crystalline melting points. Figure 3.2 shows such a screw. The first feed or conveying stage of the screw has a uniform screw root diameter and flight depth. It serves to move the dry resin pellets forward to the transition zone, heating the feed as it does so. In the transition zone, the screw root diameter increases and the screw flight depth decreases to accommodate the change from a low bulk density feed to a higher density melt. Shear heating and homogenization of the melt is accomplished in this stage. The metering zone at the front end of the screw also has a uniform flight depth, shallower than that of the feed zone. This stage acts as a melt pump to force the melt out through a nozzle into the die. For processing materials with crystalline melting points and relatively low melt viscosities like Riteflex® TPC-ET, the screw L/D ratio should be in the range of 20:1 or greater with at least 3 or 4 flights of metering zone. The feed zone should account for about half the screw length, with the remaining half equally divided between transition and metering zones. A compression ration, i.e., the ratio of flight depth in the feed zone to that in the metering zone, should be in the range 3:1 to 4:1.

Fig. 3.2 • Recommended Extruder Screw



- Feed zone L_E = (0.25 to 0.33) · L
- Compression zone L_K = (0.25 to 0.33) · L
- Metering zone L_A = (0.33 to 0.5) · L
- Flight depth ratio (or compression ratio) $\frac{t_E}{t_A}$ = 3.5 to 4
- Flight depth t_A = 2.5 mm

3.3.2 Nozzle

A simple free-flow type nozzle with an independent heater and controller is recommended. Such a nozzle requires melt compression (suckback) control on the molding machine.

3.3.3 Non-return Valves

The molding machine must have a provision to stop polymer melt from flowing back over the screw during the injection stroke. This is accomplished by means of a check ring or an internal ball non-return valve on the front end of the screw. Drawings of these valve types are shown in Figures 3.3 and 3.4.

Fig. 3.3 • Check Ring Nonreturn Valve Used on Reciprocating Screw Injection Molding Machines

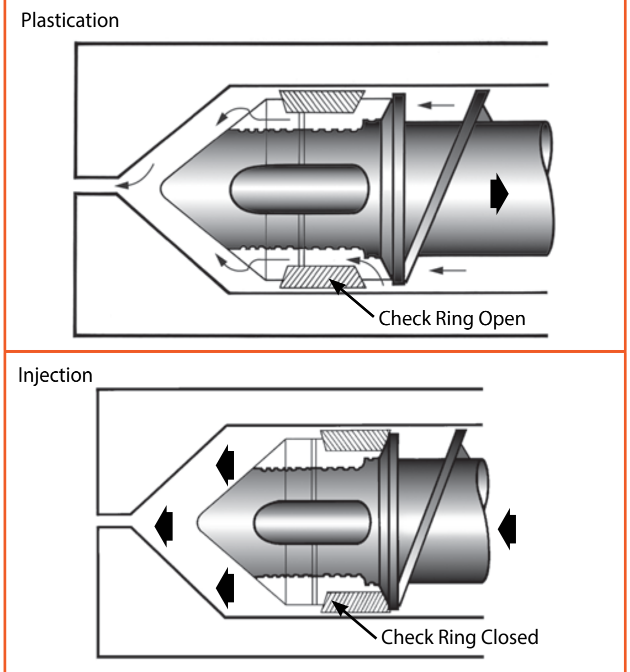
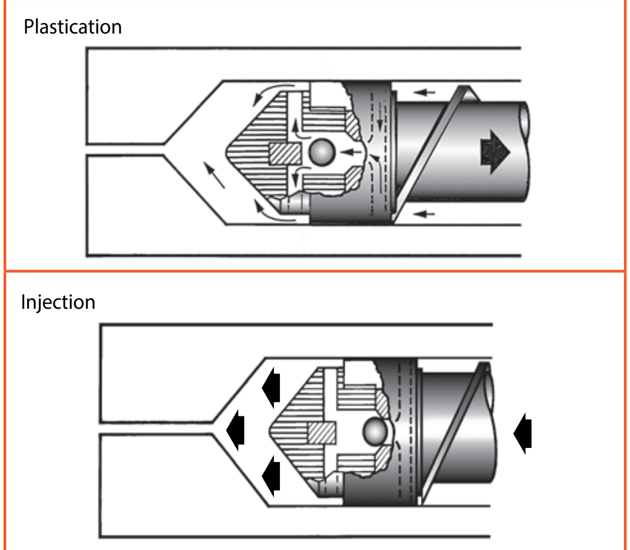


Fig. 3.4 • Internal Ball Check Nonreturn Valve Used on Reciprocating Screw Injection Molding Machines



3.3.4 Clamping Systems

The clamp keeps the mold closed by either a toggle mechanism or a hydraulic cylinder. Riteflex® thermoplastic polyester elastomers can be processed on either type. The clamp force should be 3 to 4 tons per square inch of projected surface area (including runners).

3.3.5 Mold Construction

Molds should be made from tool steel. The recommended value for mold steel hardness for Riteflex polymers is H13.

3.4 Drying

It is extremely important to thoroughly dry both virgin resin and reground material. After drying, exposure to ambient conditions prior to processing should be kept to a minimum. High moisture levels may not only cause processing problems, but also generate surface imperfections and degrade the resin enough to cause a reduction in physical properties.

3.4.1 Drying Equipment

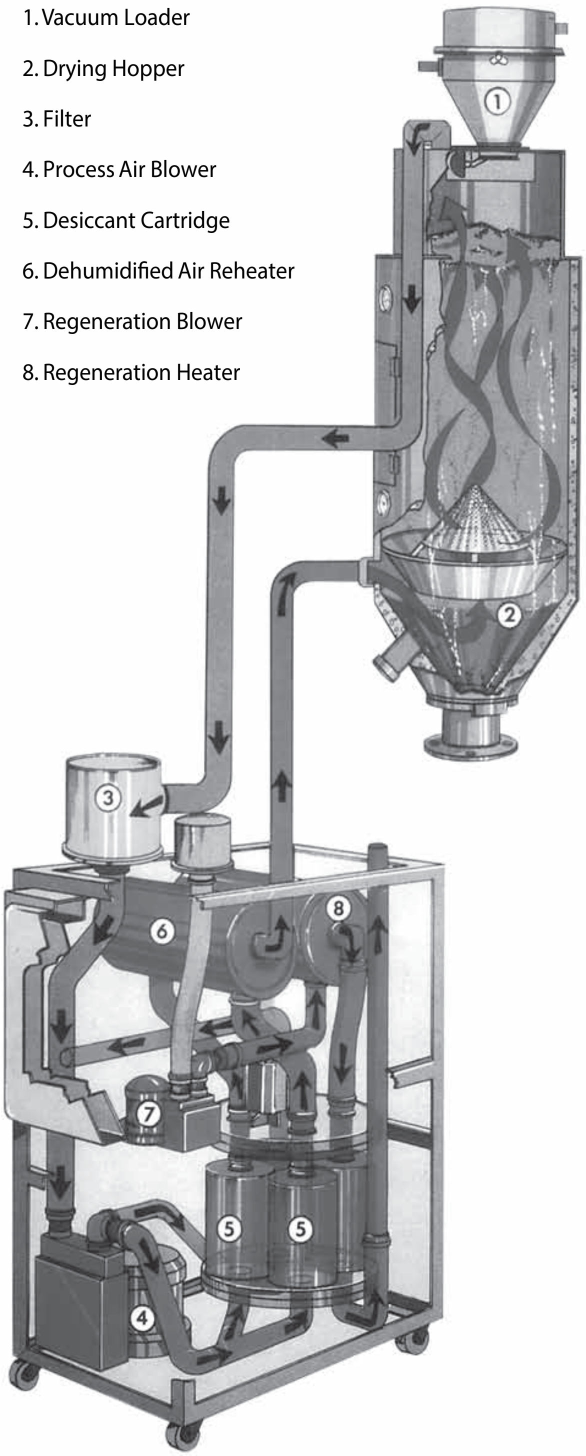
Riteflex resins should be properly dried in a dehumidifying hopper drier, such as is shown in Figure 3.5. Drying in a hot air oven is not recommended because:

- A bed depth greater than about 1 to 1-1/2 inches can result in inadequate drying
- Poor heat transfer causes long drying times and possible discoloration
- There is a risk of contamination from other material previously dried in the same oven

If there is no option but to use a hot air oven, trays should be thoroughly cleaned, as should the racking supports, and bed depth should be kept below 1 inch.

Fig. 3.5 • Hopper Dryer Unit

1. Vacuum Loader
2. Drying Hopper
3. Filter
4. Process Air Blower
5. Desiccant Cartridge
6. Dehumidified Air Reheater
7. Regeneration Blower
8. Regeneration Heater



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3.4.2 Drying Process

In hopper dryer operation, the vacuum loader drops resin into the insulated drying hopper on demand. Heated dehumidified air enters the hopper, picks up moisture as it passes through the resin bed and exits via the return line port. It is then filtered and sent through the desiccant cartridge before going to the reheater and thence back to the hopper. So that the dryer can operate continuously, ambient air is taken in and pumped by the regeneration blower through a separate heater and then fed through the exhausted desiccant cartridge, drying it out to be placed back on stream when needed. It is most important to keep the return air filter clean. If it becomes clogged, air flow through the resin bed will diminish and the resin will not be adequately dried.

3.5 Drying Guidelines

To achieve an acceptable moisture level of less than 0.05% when drying virgin or reground Riteflex® resins, drying time should be not less than four hours at temperature recommendations below in table 3.1.

3.6 Injection Molding

Injection molding is a superficially simple but operationally complex process. To obtain consistent high quality parts, molding parameters must be carefully controlled. While the following guidelines provide general molding recommendations, the molder should seek to determine optimum conditions for each specific part and the mold and machine combination being used to make it.

3.6.1 Safety and Health

TBefore starting to mold any parts from a Riteflex thermoplastic polyester elastomers, obtain and review the appropriate Material Safety Data Sheet (MSDS) for that material. An MSDS can be found on Celanese's web site http://tools.Celanese.com/tools/restricted/mbase/mcbasei/ msds.php or obtained by calling Celanese's Customer Service Department at 1-800-526-4960.

3.6.2 Processing Conditions

For softer grades (Riteflex 425 and 435), maintain mold temperature at 20°C (73°F) to minimize sticking during part ejection.

Table 3.1 • Recommended Molding Conditions for All Grades of Riteflex Thermoplastic Polyester Elastomers

Riteflex TPC-ET Grade	425	435	440	640A	655A	447 & 663	672	677
Melting Point, °C	155	185	195	170	200	212	215	218
Molding Parameter								
Mold temperature °C (°F)	20 (73)	20 (73)	24-52 (75-125)	24-52 (75-125)	24-53 (75-125)	24-53 (75-125)	31-73 (88-163)	38-93 (100-200)
Melt temperature °C (°F)	171-188 (340-370)	200-215 (390-420)	210-225 (410-435)	185-205 (365-400)	220-235 (430-460)	230-260 (445-500)	238-266 (460-510)	238-266 (460-510)
Screw speed, rpm	60-125	60-125	60-125	60-125	60-125	60-125	60-120	60-125
Back pressure, psi	0-50	0-50	0-50	0-50	0-50	0-50	0-100	0-100
Injection speed	Fast	Fast	Fast	Fast	Fast	Fast	Fast	Fast
Cushion, inches	0.125-0.25	0.125-0.25	0.125-0.25	0.125-0.25	0.125-0.25	0.125-0.25	0.125-0.25	0.125-0.25
Barrel Settings °C (°F)								
Feed Zone	154-171 (310-340)	163-182 (325-360)	185-200 (365-390)	160-177 (320-350)	199-216 (390-420)	199-216 (390-420)	232-243 (450-470)	232-243 (450-470)
Center Zone	171-182 (340-360)	182-199 (360-390)	200-215 (390-420)	177-188 (350-370)	216-232 (420-450)	216-232 (420-450)	238-249 (460-480)	238-249 (460-480)
Front Zone	171-182 (340-360)	182-204 (360-400)	200-220 (390-430)	177-193 (350-380)	216-238 (420-460)	225-250 (435-480)	243-254 (470-490)	243-254 (470-490)
Nozzle	171-188 (340-370)	200-215 (390-420)	210-225 (410-435)	185-205 (365-400)	220-235 (430-460)	230-260 (445-500)	249-260 (480-500)	249-260 (480-500)
Drying Temperature and time °C (°F)								
4 Hours	100 (212)	105 (220)	110 (230)	105 (220)	110 (230)	110 (230)	110 (230)	115 (240)

3.6.3 Mold Temperature

Begin at the lower end of the molding temperature range, using short shots. (See Table 3.1)

3.6.4 Injection and Holding Pressure

Keep injection pressure low when starting the molding cycle; this will produce short shots. Gradually increase pressure by 50-100 psi until the cavity fills completely. As complete parts are ejected from the mold, raise injection pressure approximately 100 psi, making sure the material does not flash.

3.6.5 Injection Speed

Injection speeds should be in the range of slow to medium for all grades of Riteflex® thermoplastic polyester elastomers; the injection speed of the machine should be at the medium setting.

3.6.6 Screw Speed and Cushion

Screw speed should be 60-125 rpm and the cushion/pad should be 0.125-0.250 inch (3 to 6 mm). (See Table 3.1)

3.6.7 Troubleshooting

Many processing problems are caused by easily corrected conditions such as inadequate resin drying, incorrect temperatures and/or pressures, etc. Often, solutions to these problems can be found by following the recommendations. Try them in the order in which they are listed under each problem category.

3.6.7.1 Troubleshooting Guide – Injection Molding

Short Shots, Poor Surface Finish

- Increase injection pressure
- Decrease cushion
- Raise cylinder temperature
- Raise mold temperature
- Increase size sprue/runners/gates
- Increase injection speed
- Increase/decrease feed to maintain proper cushion
- Check cavity vents for blockage
- Increase booster time
- Increase screw speed
- Increase back pressure

Flashing

- Lower material temperature by:
  - – Lowering cylinder temperature
  - – Decreasing screw rotational speed
  - – Lowering back pressure
  - – Decrease injection pressure
- Decrease overall cycle time
- Check mold closure for possible obstruction on parting surface line
- Check machine platens for parallelism
- Check parting line of mold for wear

Splay Marks

- Dry the material before use
- Check for contamination such as water or oil leakage into the mold cavity
- Check for drooling
- Decrease injection speed
- Raise mold temperature
- Lower material temperature by:
  - – Lowering cylinder temperature
  - – Decreasing screw rotational speed
  - – Lowering back pressure
  - – Lower nozzle temperature
  - – Decrease overall cycle time
  - – Open the gate(s)

Discoloration

- Purge heating cylinder
- Lower material temperature by:
  - – Lowering cylinder temperature
  - – Decreasing screw rotational speed
  - – Lowering back pressure
  - – Lower nozzle temperature
  - – Decrease overall cycle time
  - – Check hopper and feed zone for contamination
  - – Provide additional vents in mold
  - – Move mold to machine with smaller shot size (50-75% of capacity)
  - – Check ram and feeding zone for proper cooling

Nozzle Drool

- Lower nozzle temperature
- Lower material temperature by:
  - Lowering cylinder temperature
  - Decreasing screw rotational speed
  - Lowering back pressure
- Decrease residual temperature in cylinder by:
  - Reducing plunger forward time and/or back pressure
  - Increasing decompression time (if machine has this control)
- Decrease overall cycle time
- Reduce back pressure
- Decrease die open time
- Use nozzle with positive shut-off valve
- Dry the material before use
- Use nozzle with smaller orifice
- Use reverse-taper nozzle or nozzle valve

Nozzle Freeze-off

- Raise nozzle temperature
- Decrease cycle time
- Raise mold temperature
- Use nozzle with larger orifice

Burn Marks

- Decrease injection speed
- Decrease booster time
- Improve venting in mold cavity
- Change gate position and/or increase gate size to alter flow pattern

Sticking in Cavities

- Decrease injection pressure
- Decrease injection speed
- Decrease booster time
- Decrease injection hold time
- Increase mold closed time
- Lower mold temperature
- Lower cylinder and nozzle temperature
- Check mold for undercuts and/or insufficient draft

Sticking on the Core

- Increase injection pressure
- Increase booster time
- Increase injection speed
- Decrease mold closed time
- Decrease core temperature
- Check mold for undercuts and/or insufficient draft

Sticking in Sprue Bushing

- Decrease injection pressure
- Decrease hold time
- Increase mold closed time
- Raise nozzle temperature
- Check size and alignment of holes in nozzle and sprue bushing (holes in sprue bushing must be larger)
- Provide more effective sprue puller

Weld Lines

- Increase injection pressure
- Increase injection forward time
- Increase injection speed
- Raise mold temperature
- Raise material temperature
- Raise cylinder temperature by:
  - Increasing screw rotational speed
  - Increasing back pressure
- Vent the cavity in the weld area
- Provide an overflow well adjacent to weld area
- Change gate position to alter flow pattern

Unmelted Pellets

- Increase melt temperature
- Increase back pressure
- Dry/preheat the resin
- Use a press with proper screw design (see “Screw Design” in section 3.3.1)
- Check to be sure that the nonreturn check valve is working properly to prevent back flow
- Move the mold to a press with a larger shot capacity

Sinks and Voids

- Increase injection pressure
- Increase injection hold time
- Use booster and maximum ram speed
- Raise mold temperature (for voids only)
- Lower mold temperature (for sinks only)
- Decrease cushion
- Increase size of sprue/runners/gates
- Relocate gates closer to heavy sections

Warpage, Part Distortion

- Equalize temperature in both halves of the mold (eliminate hot spots)
- Check mold for uniform part ejection
- Check for proper handling of parts after ejection
- Increase ejection hold time
- Try increased pressure and decreased pressure
- Increase mold closed time
- Lower material temperature by:
  - Lowering cylinder temperature
  - Decreasing screw rotational speed
  - Lowering back pressure
- Try differential mold temperatures to counteract warp
- Fixture the part and cool uniformly
- Check for contamination

Brittleness

- Dry the material before use
- Check for contamination
- Lower material temperature by:
  - Lowering cylinder temperature
  - Decreasing screw rotational speed
  - Lowering back pressure
  - Reduce amount of regrind in feed

Delamination

- Raise temperature of mold and/or material
- Check for and eliminate any contamination
- Dry the material before use
- Increase injection speed

Poor Dimensional Control

- Set uniform cycle times
- Maintain uniform feed and cushion from cycle to cycle
- Fill the mold as rapidly as possible
- Check machine's hydraulic and electrical systems for erratic performance
- Increase gate size
- Add vents

3.7 Extrusion

Like injection molding, the extrusion process involves using a screw and barrel assembly to melt polymer. The melt is then continuously pumped through a die to form an extrudate of consistent cross-section such as film, sheet or tubing. When extruding an unfamiliar grade or if problems arise during processing that cannot be corrected using the troubleshooting guide on page 26, contact your local Celanese representative or call 1-800-833-4882.

3.7.1 Safety and Health Information

Before starting the extrusion process, obtain and read the appropriate polyester Material Safety Data Sheet (MSDS) for detailed safety and health information. They may be found on Celanese's web site http://tools. Celanese.com/tools/restricted/mbase/mcbasei/msds.php or by calling Customer Service at 1-800-526-4960. Use process controls, work practices and protective measures described in the MSDS to control workplace exposure to dust, volatiles or vapors.

3.7.2 Drying Requirements

Riteflex® thermoplastic polyester elastomers must be dried to proper moisture levels below 0.05% before extruding. The information and recommendations in sections 3.6 and 3.7 are also applicable to the extrusion of Riteflex® TPC-ET.

3.7.3 Equipment Construction

For maximum resistance to abrasion and corrosion, extruder screws, breaker plates, screens, adapters and dies should all be made of corrosion-resistant metals.

3.7.4 Extruder Barrel

Standard extruders, having barrel length-to-diameter ratios equal to or greater than 30:1, are recommended for processing polyester resins such as Riteflex TPC-ET. Higher L/D ratios provide a more homogenous melt and a higher throughput for a given extruder size.

3.7.5 Screw Design

Screw designs for Riteflex® polymers should have a compression ratio between 3:1 and 4:1 (the ratio between the feed zone channel depth and the metering zone channel depth). As shown in Fig. 3.6, the feed zone screw channel should be approximately 0.400 inch deep, while the metering zone screw channel should gradually reduce to approximately 0.100 inch, with the overall length-todi meter value being 30:1 or greater. Feed zone length should comprise at least 25% of the total screw length. A long and gradual transition section of at least 25% is also recommended, since sharp or short transition sections can cause high barrel pressures and higher melt temperatures due to high shear (especially at higher screw speeds).

While not required, Riteflex TPC-ET resins may be extrusion-processed using barrier-flighted screws. Such screws are thought to improve melt homogeneity, but may also increase resin degradation by increasing both residence time in the barrel and mechanical work input to the polymer melt. Accordingly if a barrier-flighted screw is used in extrusion of Riteflex TPC-ET resins, careful attention should be paid to melt temperatures.

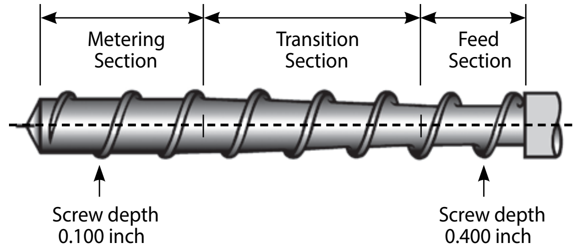
Length of the metering zone and the screw depth are important to maintain optimum control of melt temperature and output consistency. Too long or too shallow a metering zone increases the melt temperature due to shear, while short and deep metering zones can result in pressure fluctuations (surging) and nonuniform output.

Extrusion processing requirements can often be met by so-called "typical" polyethylene screws, or by those designed for nylon, where the transition zone is of proper length. For Riteflex TPC-ET, recommended lengths of the feed, transition and metering zones as a percentage of the total screw length should be approximately 25%, 25% and 50% for the feed, transition and metering sections respectively.

3.7.6 Breaker Plate and Screens

Screens (usually 80-100 mesh) are recommended for Riteflex thermoplastic polyester elastomers. Screens are used to protect the die from being damaged by foreign matter and to increase backpressure, especially when mixing fillers or pigments. A breaker plate, usually incorporated at the end of the screw, is used to support the screens.

Fig. 3.6 • Typical Screw Design



3.7.7 Dies

Dies must be streamlined, having no areas where material can be trapped or hung up. Thermoplastic materials exposed to high temperatures for prolonged periods degrade and not only contaminate subsequent extruded product with black or brown specks, but also affect uniform machine operation.

3.7.8 Processing Conditions

Table 3.2 shows recommended processing conditions for the various grades of Riteflex TPC-ET.

3.7.9 Processing Procedures

Final extrudate quality can be greatly affected by even small changes in the temperature of the melt. Generally speaking, the slower the extrusion rate (longer residence), the greater the effect these changes will have. Balancing thermal heating against shear energy input with variable voltage (or proportioning) controllers is a good way to keep the melt thermally homogenous.

Pressure changes during production indicate changes in viscosity and output rate of the melt. Diaphragm type transducers, which measure fluctuations in pressure, are recommended.

3.7.10 Startup

When starting up an empty machine, set the temperature controllers for the die, adapter and barrel using the appropriate temperatures shown in Table 3.2. When these reach their operating temperatures, bring the remaining barrel temperatures up to the proper settings. After they have held the proper temperatures for 20 to 30 minutes, turn the screw on at low RPM and start feeding Riteflex polymer into the hopper. Carefully check both the ammeter and pressure gauges. As melt appears at the die, it may be hazy. At that time, temperature and head pressure should start to stabilize.

3.7.11 Purging and Shutdown

A machine should never be shut down while Riteflex® TPC-ET remains in it. As recommended in section 3.1.4, medium-to-high density polyethylene should be used to purge the extruder. Temperature controllers should remain set at running conditions. Purge all of the polyester from the extruder. Continue running until all purge material is out of the machine and then shut down.

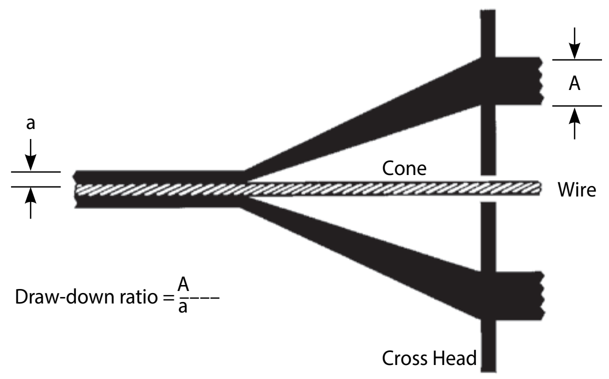
3.7.12 Wire Coating

In wire coating, an extruded tube of TPC-ET forms a cone at the die, into which the wire passes. The wire is completely coated as it passes through the crosshead.

As shown in Figure 3.7, the draw-down ratio is the ratio between the cross-sectional area of the tube wall at the die face to the cross-sectional area of the finished coating. Draw-down ratio for Riteflex polymers should be between 6:1 and 10:1.

Since streamline design is critical to avoid degradation, the die face must have no areas where material can hang up. Cone length (the distance between the die face and the point where the Riteflex polymer coats the wire) is very important. It is generally between 1.5 and 2 inches (37 and 50 cm), and is most precisely defined by trial and error, as too long a cone may sag and set before drawing is complete, while too short a cone can lead to pinholes and tearing.

Fig. 3.7 • Polyester in Wire Coating



3.7.13 Cooling Trough

The coated wire is air cooled to shrink the coating onto the wire and then passes into a water-cooling bath to harden the coating. A balance between air-cooling and cone length helps ensure the desired integrity of the coating. Water temperature in the cooling trough is critical. If too cold, the coating can be frozen into an amorphous state with its attendant possibility of post-crystallization. This can cause wire to take a set on a spool or winding reel. A water temperature between about 40°C and 60°C (100 -130°F) avoids postcrystallization and eliminates or minimizes spool-set, giving better mechanical properties to the wire.

Table 3.2 • Recommended Extrusion Processing Conditions for the Various Grades of Riteflex TPC-ET

Riteflex TPC-ET Grade	425	435	440	640A	655A	447 & 663	672	677
Melting Point, °C	155	185	195	170	200	212	215	218
Recommended Temperature, °C)								
Zone 1	155-170	185-200	195-210	170-185	205-220	215-230	225-240	225-240
Zone 2	170-180	190-205	200-215	175-190	210-225	220-235	230-245	230-245
Zone 3	170-190	200-210	205-220	180-195	215-230	225-240	235-250	235-250
Zone 4	170-190	200-215	205-220	180-200	215-230	225-240	235-255	235-255
Zone 5	175-190	200-215	210-225	180-205	220-235	230-250	235-260	235-260
Adapter/Breaker Plate	175-190	200-215	210-225	180-205	220-235	230-250	235-260	235-260
Die	175-190	200-215	210-225	180-205	220-235	230-250	235-260	235-260
Melt Temperature	175-190	200-215	210-225	180-205	220-235	230-250	235-260	235-260
Drying Temperature and time °C (°F)								
4 Hours	100 (212)	105 (220)	110 (230)	105 (220)	110 (230)	110 (230)	110 (230)	115 (240)

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3.7.14 Tube Extrusion

Riteflex® TPC-ET can be readily extruded into tubing up to 3/8 inch (9.5 mm) diameter without requiring special equipment. Melt temperature control is important. If the temperature is too high, low melt strength can cause irregular wall thickness, while if it is too low, poor tube finish, uneven dimensions and weld lines can result. Use the temperatures given in Table 3.2 as a starting point. Dies like those used in wire coating are employed in free extrusion of tubing, with a general set-up as shown in Figure 3.8. Inside the water trough, the extruded tube of resin is pulled through one or more sizing rings to control the outer diameter.

3.7.15 Vacuum Tank

For tubing of diameters greater than 0.5 inch (12.7 mm), a vacuum-sizing tank is generally employed. The vacuum in the water-cooling trough causes the tube to expand to the sizing die set to control the outside diameter of the tube. As with all tube extrusion, control of melt and vacuum tank temperatures is important because Riteflex TPC-ET has a relatively narrow range between melting and freezing.

3.7.16 Sheet Extrusion

As shown in Figure 3.9, Riteflex TPC-ET sheet may be extruded with standard equipment, typically including an extruder, sheet die, polishing rolls, pull rolls, edge trim knives and winder. A flex lip coat-hanger die is best suited for sheet extrusion, as it does not have the stagnant areas found in "T" dies. As with other melt processing equipment for Riteflex TPC-ET, such stagnant areas can cause melt hang-up and material degradation. The die flex lip is adjusted to provide uniform melt flow across the face of the die. Good die temperature control is also necessary.

The air gap should be as small as possible and the melt bank (between the nip rolls) should also be small enough to avoid stress in the sheet (which can be caused by an excessive melt bank), but not so small as to cause nonuniform sheet thickness.

3.7.17 Polishing Rolls

These rolls are used to improve the surface finish of the sheet. Normal temperature settings are between 40°C and 80°C (100°F and 175°F), with lower temperatures being used for the lower Durometer grades. The final roll temperatures and the heat transfer can be strongly affected by the internal cleanliness of these rolls.

Fig. 3.8 • Polyester in Tube Extrusion

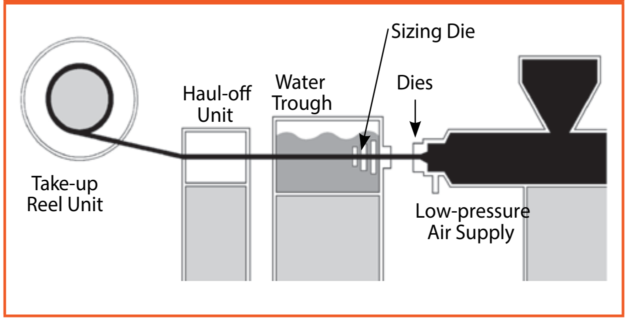


Fig. 3.9 • Polyester Sheet Extrusion

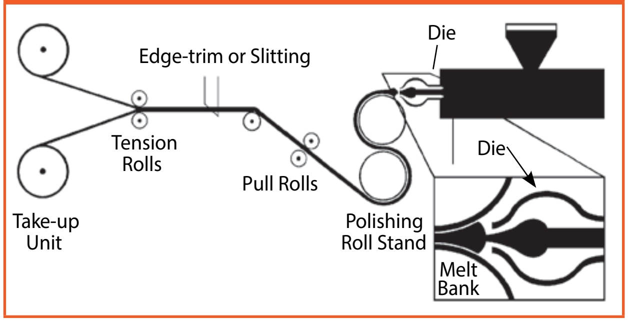
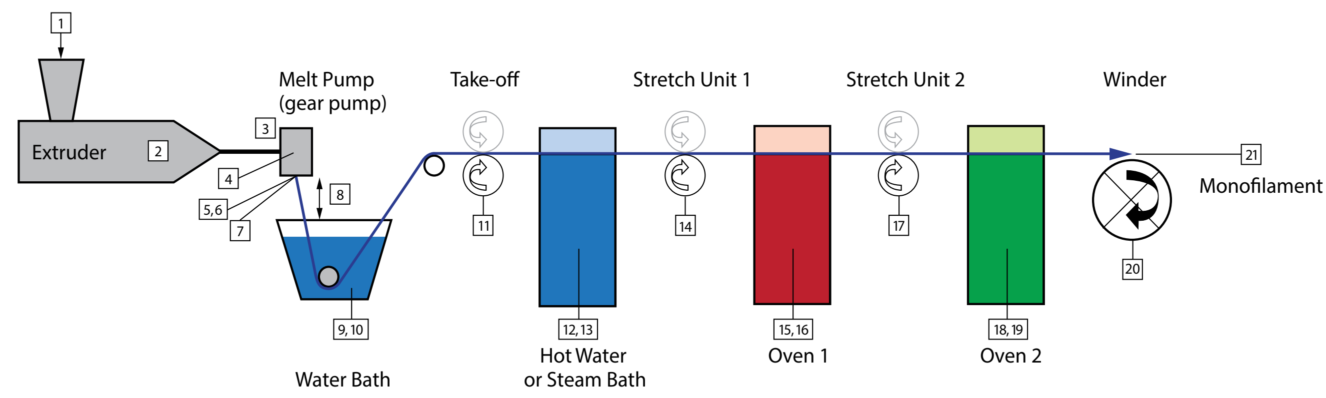


Table 3.10 • Guideline for the Manufacturing of Elastic Monofilaments from Riteflex TPC-ET Resins					
No.	Parameter (Unit)	Value	No.	Parameter (Unit)	Value
1	Material Dosage (kg/h)	Variable	12	Temperature Hot Water or Steam Bath (°C)	90-100
2	Extruder Temperatures (°C)	RT up to ca. 260	13	Residence Time Hot Water or Steam Bath	—
3	Melt Temperature (°C)	Max. 270 for Riteflex 655	14	Velocity of 1st Stretch Unit (m/min)(→Stretching)	e.g. 120 (Stretch Ratio 4:1)
4	Melt Pump (rpm)	Variable	15	Temperature Oven 1 (°C)	ca. 140
5	Die Plate (number of holes)	Variable	16	Residence Time Oven 1	—
6	Bore Diameter (mm)	e.g. 1-5	17	Volocity 2nd Stretch Unit (m/min)(→ Shrinkage)	e.g. 114 (5% Shrinkage)
7	Extrusion Velocity (m/min)	e.g. 3	18	Temperature Oven 2 (°C)	Cold/RT
8	Distance to Water Bath (cm)	e.g. 1	19	Residence Time Oven 2	—
9	Water Bath Temperature (°C)	50-70	20	Winding Speed (m/min)(→ Tension)	e.g. 117 (2.5% Tension)
10	Water Bath Residence Time	—	21	Monofilament Diameter (mm)	e.g. 0.2-1.2
11	Take-off Speed (m/min) (→ Spin Draft)	e.g. 30 (Draw Down Ratio 1:10)			



3.7.18 Film Extrusion

Extrusion cast films can be prepared from Riteflex® thermoplastic polyester elastomers with Shore D hardnesses of 40 or higher. Processing should start with the recommended extrusion temperatures for the grade being used as given in Table 3.2. These conditions should then be adjusted to provide the best feed quality for the downstream film handling equipment. Because tackiness is retained to quite low temperatures in films made with low hardness grades, unmodified resins of lower hardness levels are not recommended for extrusion casting. Blown films can also be made with Riteflex TPC-ET. Again, the tackiness of unmodified low hardness resins may cause self-adhesion in grades with hardness values below 40. If there are problems with material sticking to casting rolls or to itself on take-up rolls, a slip and/or release agent can be added to the polymer at the feed hopper.

3.7.19 Extrusion Troubleshooting for Riteflex® Polymers

As with injection molding, many extrusion processing problems are caused by easily corrected conditions such as inadequate resin drying, incorrect temperature and/or pressures and so on. Often solutions to these problems can be found by following the recommendations in Table 3.3. Try them in the order in which they are listed under each problem type.

3.8 Monofilament

Riteflex TPC-ET resins can be used to prepare monofilaments with a range of properties. The final monofilament properties, particularly elastic recovery, depend greatly on drawing equipment and conditions. As with film extrusion, initial extruder conditions should be as recommended in Table 3.3, with subsequent adjustment optimized to suit the drawing and other monofilament processing steps, details see Fig. 3.10.

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Table 3.3 • Troubleshooting Guide, Extrusion Processing of Riteflex® TPC-ET

Problem	Typical Cause	Corrective Action
Blistering	Moisture in feedstock	■ Dry feed to proper moisture level before use
	Cooling too quickly	■ Slow down the cooling rate
Bubbles	Trapped air	■ Increase rear barrel temperature ■ Use correct screw ■ Increase back pressure ■ Check controllers
	Resin degraded by heat or hold-up time	■ Lower temperatures ■ Increase extrusion rate ■ Use correct screw ■ Check for hang-ups in barrel and die ■ Check heaters, thermo-couples and controllers
	Resin moisture too high	■ Dry feed to proper level before use
Breaks, tears, pinholes	Excessive draw-down	■ Reduce draw-down ratio
	Short cone, draw too fast	■ Lengthen cone, reduce draw rate
	Material too cold	■ Raise melt or die temperature
	Poor blend of pigments or fillers	■ Blend more thoroughly before use ■ Use correct screw ■ Reduce filler or pigment loading
Coatings don't stick	Cooling too fast	■ Lengthen air gap ■ Reduce extrusion rate
	Resin degraded	■ See "Bubbles" above
	Cone too long	■ Shorten cone
Contaminated extrudate	Poor handling of feed	■ Protect resin, keep clean
	Dirty extruder	■ Remove all resin, clean machine thoroughly
	Extruder corrosion	■ Use corrosion-resistant metals for melt contact
	Dirty regrind	■ Clean extruder ■ Use clean regrind, dried to proper level

Table 3.3 • Troubleshooting Guide, Extrusion Processing of Riteflex TPC-ET continued

Problem	Typical Cause	Corrective Action
Diameter fluctuates	Take-off speed variation	■ Check tension control ■ Increase pressure on tractor heads
	Surging	■ Increase screw speed ■ Increase back pressure with screen pack
	Temperature cycling	■ Use variable transformers with time proportioning controllers. Make sure controllers are mostly "ON"
	Draw rate too low	■ Reduce cone length
	Excessive tension on tubing sizing plates or die	■ Shorten sizing die length (eliminate a plate or two) ■ Use water or water and soap to lubricate sizing die
	Uneven feed to extruder – check extrusion rate uniformity and head pressure	■ Lower rear barrel temperature ■ Cool hopper throat
	Moisture in feed	■ Dry material to proper level before use
Out of round (deformed or nonconcentric)	Misshapen die	■ Replace die ■ Correct guider tip
	Varying cooling rate	■ Adjust water submersion depth ■ Center the die
	Coating sags and sets	■ Lower melt temperature ■ Increase drawdown rate (increase extruder speed, increase drawdown ratio, or shorten cone length) ■ Cool faster (reduce air gap or increase output)
	Excessive take-up pressure	■ Put slack in wire line ■ Reduce capstan tension ■ Lengthen cooling so extrudate sets before take-up
	Die off-center	■ Center die
	Guider tip too flexible	■ Remove all resin(s) and clean
	Extruder corrosion	■ Use corrosion-resistant metals for melt contact
	Dirty regrind	■ Clean extruder ■ Use clean regrind, dried to proper level

Table 3.3 • Troubleshooting Guide, Extrusion Processing of Riteflex® TPC-ET continued

Problem	Typical Cause	Corrective Action
Out of round (buckling or folding)	Hang-up on die face or guider tip	■ Remove imperfections
	Melt tension varies	■ Make hole in guider tip smaller or center the die
	Draw rate too fast	■ Lengthen cone (reduce vacuum)
	Draw-down ratio too high	■ Reduce draw-down ratio
	Ratio of die size to coated wire size is too low in comparison with ratio of guider tip size to wire size	■ Increase draw ratio
Extruder overloaded	Feed section flights too deep	■ Use screw with shallower feed ■ Use lubricant
	Rear temperature too low	■ Increase rear temperature ■ Check rear zone thermocouple and controller
	Pellets wedge between flight land and barrel	■ Increase rear temperature
Shrink-back	Wire stretching	■ Reduce tension on wire
	Too much orientation during drawdown	■ Preheat the wire ■ Increase draw rate (shorter cone) ■ Reduce draw-down ratio ■ Enlarge air gap or reduce quench rate ■ Increase die and melt temperatures
Rough Finish	Contamination	■ See "Contaminated Extrudate"
	Dirty/poorly finished die	■ Inspect die and tip, remove burrs
	Melt fracture caused by excessive shear	■ Increase die temperature ■ Widen die opening ■ Reduce extrusion rate ■ Increase melt temperature
	Wrong draw rate	■ Adjust cone length
	Material on die face	■ Clean die face
	Wire vibrating	■ Use damping pads or guides

Table 3.3 • Troubleshooting Guide, Extrusion Processing of Riteflex® TPC-ET continued

Problem	Typical Cause	Corrective Action
Surging	Slipping drive belts	■ Secure belts
	Inadequate melt reservoir	■ Change screw ■ Reduce screw speed ■ Check for temperature cycling ■ Decrease die opening ■ Increase back pressure
	Bridging in feed section	■ Check feed zone controller ■ Reduce rear temperature ■ Increase cooling water to feed throat
	Bridging in transition zone	■ Switch to screw with longer feed section ■ Increase temperature in rear zone
Unmelted material in extrudate	Barrel temperature too low	■ Increase temperature settings
	Compression ratio of screw too low	■ Increase back pressure ■ Change screw
	Heater watt density too low	■ Increase wattage ■ Change heater bands
	Cold spots in extruder sections	■ More heat to area from barrel extension to die neck ■ Check thermocouples and controllers for accuracy ■ Insulate exposed areas to cut heat loss
Sheet sticking to roll	Roll too hot	■ Reduce roll temperature
	Material too hot	■ Reduce material temperature ■ Check controller heaters and thermocouples

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4. Part and Mold Design

4.1 Introduction

A complex interplay exists between material selection, part design and mold design. The right choice of material is driven by a focus on the intrinsic properties that are needed for the final part to operate as a system component. While the elastomeric attributes of Riteflex® TPC-ET enable somewhat less stringent requirements in such areas as corner radii and undercut tolerance, typical plastics design principles should still be followed with these resins. A first step is to establish performance criteria for the final part and component parts. Factors to be considered include:

- Functional requirements of part and system
- Ability to simplify design or eliminate parts by using Riteflex TPC-ET
- Environmental stresses to be withstood – chemical, thermal, radiation
- Time-dependent criteria – fatigue, creep and compression set
- Aesthetic requirements – color, surface finish, possible decoration
- Regulatory constraints to be met
- Any post-molding processing or assembly steps
- Projected cost of part and system

Each factor can be expanded in such detail as best fits the application and then a design can be drawn. It is always eferable to go from the first design to making a prototype art by machining or prototype molding in an inexpensive mold cut from aluminum or a suitable alloy. Molding is preferable to machining, because it not only avoids machining marks, but also enables gate location investigation. Parts from this step can then be tested in situations as close to the intended use as possible and specifications written.

4.1.1 Material Selection

Once it is determined that the part performance requirements will be met by Riteflex TPC-ET, a specific grade can be selected. The broad property range available from the Riteflex TPC-ET product line enables the best balance of properties for the application to be readily attained.

4.1.2 Wall Thickness

Wall thickness, particularly in semi-crystalline resins, should be kept to the minimum required for part performance. Apart from higher material cost and processing time and cost, thick walls can introduce problems such as internal voids and external sink marks. Thick-walled parts, up to 0.5 inch (12.7 mm) can of course be molded from Riteflex TPC-ET. Appropriate sprue runner and gate designs should be cored to reduce the effective thickness, which is consistent with retaining adequate properties. For small and medium-sized parts, a practical wall thickness can be as low as 0.03 inch (0.7 mm). But for larger parts a wall thickness of 0.06 inch (1.5 mm) or greater is recommended.

In addition to being as thin as possible, the wall thickness should also be uniform. Thick and thin sections in the same part can result in slight differences in density within the sections. This, combined with differences in cooling rate between thick and thin areas can cause voids, sinks and warpage. If for some reason the thicker sections cannot be cored out, a gradual transition should be made from thick to thin walls.

4.1.3 Ribs

Ribbing is frequently used to reduce part wall thickness, weight and cost. It is also used to increase part strength and stiffness, improve flow paths and prevent warpage. However, ribs can cause sink marks and induce warpage if not properly designed and located in the part. Ribbing should therefore be employed only when the benefit is reasonably certain. Where ribs are required, the thickness should not exceed 50% of the adjacent wall thickness to prevent voids, sink marks or other distortions. To further minimize sink marks, the rib contour should match the exterior contour of the part, and rib height should be no more than 0.75 inch (19 mm).

Where sink marks are not a concern, rib thickness may be 75% to 100% of the adjacent wall thickness and may be located anywhere extra strength is desired. However, ribs of this thickness can change the final shape and/ or dimensions of the part due to shrinkage in the rib. Fillets should be used where ribs join the part wall to minimize stress concentration and provide additional strength. To facilitate part ejection from the tool, adequate draft should be provided on both sides of the rib.

4.1.4 Bosses and Studs

Bosses and studs are frequently used to reinforce around holes, provide mounting or fastening points. Guidelines to be considered when designing a boss or stud include:

- The height should not be more than twice the diameter.
- Adequate draft is needed for easy part ejection.
- Where the boss joins the wall, filleting eases fill, strengthens the part and helps disguise sink.
- For a solid boss, the diameter should be less than the thickness of the wall from which it protrudes. For this reason, bosses should be cored out so the boss sidewall-thickness is less than the main wall thickness. Core pin ends should be radiused to eliminate sharp corners and minimize sink tendency.
- Bosses and studs are best located where the surface contour changes sharply. A bubbler on the cavity side of the mold opposite the boss will often eliminate or minimize sink in the outside wall.
- For longer bosses and studs, venting should be provided to release air at the bottom of the cavity.
- For auto body components, the length of the mounting boss(es) should not provide more than 0.125 inch (3.2 mm) clearance between the end of the boss and the mounting bracket or auto frame. This will avoid dimpling" of the part by the boss being pulled inward.
- Mounting bosses adjacent to a side wall should be cored out to avoid unnecessarily thick sections.
- Ribs can be used to reinforce free-standing bosses and facilitate material flow into the boss.
- Ejector sleeves should be employed to prevent boss hang-up in the mold cavity. To effectively prevent hang-up, the stroke of the ejector sleeve should be at least 0.75 of the length of the boss.

4.1.5 Fillets and Radii

Sharp corners should always be avoided in molded plastic parts, even in relatively ductile materials such as Riteflex® TPC-ET. Such sharp corners cause poor flow patterns and can lead to high molded-in stresses and consequent reduction of mechanical properties. Radiusing and filleting are recommended for all corners to facilitate resin flow in the part, minimize stress concentration and enable easier part ejection. Inside and outside corners should be rounded with a radius of 25% to 75% of the adjacent wall thickness.

4.1.6 Tolerances

Because of some variability in the material, the molding process or because of changes in the operating environment, injection molded thermoplastic parts are subject to dimensional variations greater than those found with machined metal parts. To avoid excessive molding and processing costs, part designers should determine if very tight tolerances are really necessary and if they can be economically justified. It may be unreasonable to specify close tolerances on a part that will be exposed to a wide temperature range since temperature-driven dimensional changes can be many times greater than specified tolerances.

See shrinkage table 2.1 for dimensional tolerances that can routinely be held with Riteflex TPC-ET.

4.1.7 Threads

Internal or external threads can be molded in Riteflex TPC-ET, but it may not be possible to machine threads in the softer grades because of material "squirm." Standard thread systems can be used, but coarse threads are preferable to fine. Threads finer than 28 pitch should not be specified. Roots and crests of all threads should be rounded to reduce stress concentration and provide increased strength. A rounding radius of 0.005-0.10 inch (0.1-0.3 mm) is recommended. The bearing area for the screw head should be chamfered.

4.1.8 Holes

Through or blind holes may be readily produced in any shape. However, through holes are easier to produce because the core pin can be supported at both ends. A core pin supported at only one end can be deflected by forces exerted in molding. The depth of a blind hole should be limited to about twice its diameter.

4.1.9 Draft

Plastic parts must generally be designed with some degree of taper in the direction of mold movement to facilitate ejection from the tool. This taper is called draft in the line of draw. The deeper the draw, i.e., the greater the depth of the cavity, the more draft will be required. For the harder grades of Riteflex® TPC-ET, a draft angle of at least 1/2° per side is recommended. For the softer grades, a draft angle of as much as 2° per side may be needed.

4.1.10 Surface Finish

Because Riteflex polymers flow well and possess a degree of crystallinity, they can provide good replication of surface features, enabling a wide variety of surface finishes to be achieved. The corollary of this is that if a high gloss is required, mold surfaces must be highly polished.

4.1.11 Molded-in Inserts

Molded-in inserts may be used with Riteflex TPC-ET. The corners of such inserts should be radiused, and they should be rounded on the blind end. Torque retention projections from the insert should also be radiused and any knurling should be of a coarse pattern.

4.2 Mold Design

Riteflex TPC-ET may be successfully molded in conventional two- and three-plate molds and in stack molds. A wide variety of hot runner and insulated runner systems may also be successfully employed.

4.2.1 Mold Materials and Construction

Standard industry principles for good mold design and construction should be followed in building molds for processing Riteflex TPC-ET resins. Mold bases should be made from H-13 tool steel, a grade that combines strength and toughness with good machining and polishing qualities. Generally supplied annealed, it may be hardened to 54 Rockwell C and exhibits very low distortion during the hardening process.

A mold base should be sturdy enough to fully support cavities and cores without buckling retainer plates during injection molding. The size of the base should be such as to provide adequate space for cooling water channels sufficient to maintain a uniform mold temperature throughout.

4.2.2 Mold Surface Finish

Thanks to the good surface feature replication capabilities of Riteflex TPC-ET, a wide variety of cavity surface finishes may be effectively employed. Of course, as the part surface can be no glossier than the tool surface, the mold surface must be highly polished if a high-gloss finish is desired.

A dulled or matte surface may be created by sandblasting the cavity surface. However, on prolonged molding, the surface may develop some degree of polish, which will make the part surface somewhat non-uniform. If the non-uniform surface becomes objectionable, further sandblasting will be needed.

Various mold surface treatments such as etching or embossing may be used to provide a desired surface appearance – cross-hatching, for instance – on the molded part. Part numbers and material identification codes are commonly molded onto parts by embossing or debossing. The location of ejector (knockout) pins should be chosen so as to avoid producing marks on any portion of the part surface that is required to have a good appearance.

4.2.3 Sprue Bushings

Standard sprue bushings with a taper of 2.5° per side give satisfactory performance with Riteflex® TPC-ET resins. To facilitate ejection of the sprue, the sprue diameter should be larger than the mating end of the molding machine nozzle. The end of the sprue bushing, which mates with the runner, should be well radiused and should be equal in diameter to the runner.

Provision should be made opposite the junction of the sprue and runner for a cold slug well and for a standard design sprue puller. The sprue puller pin should be kept below the runner system to prevent any interference with resin flow.

Secondary sprues used for gating in three-plate molds should have a taper of 2° to 3° and should also be radiused where they join the runner. The sprue size must be larger than the maximum wall thickness of the molded part.

4.2.4 Conventional Runners

For most efficient flow with least frictional drag, full round runners are strongly recommended for molding of Riteflex TPC-ET resins. If this cannot be done, trapezoidal runners are the second best choice. Generous radii should be provided in the runner system where the sprue joins the runner. Suggested sizes for full round runners are given in the table below.

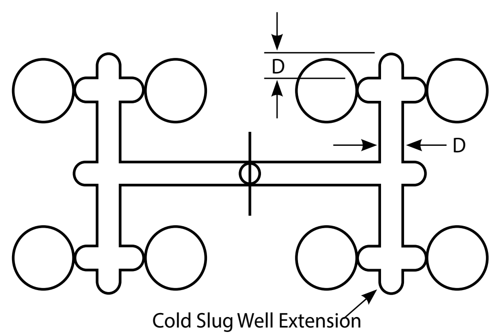
Table 4.1 • Sizes for Full Round Runners

Part Thickness, in (mm)	Runner Length, in (mm)	Min. Runner Diameter, in (mm)
0.02-0.06 (0.5-1.5)	2 (<50)	0.0625 (1.6)
0.02-0.06 (0.5-1.5)	2 (>50)	0.125 (3.2)
0.06-0.15 (1.5-3.8)	4 (<100)	0.125 (3.2)
0.02-0.06 (0.5-1.5)	4 (>100)	0.1875 (4.8)
0.16-0.25 (3.8-6.4)	4 (<100)	0.25 (6.4)
0.16-0.25 (3.8-6.4)	4 (>100)	0.3125 (7.9)

On multiple-cavity molds with primary and secondary runners, the primary runner should extend beyond its intersection with the secondary runner in order to provide a cold slug well for the runner flow front. The extended length should be at least equal to the runner diameter.

Runner length should be as short as possible consistent with melt delivery needs. For dimensional control in multi-cavity molds, the runner system should be balanced to provide equal flow distances to each cavity. Family (heterocavity) molds are in general not recommended for production of close tolerance parts.

Fig. 4.1 • Balanced Runner and Cavity Layout



4.2.5 Runnerless Molds

Runnerless molds, as the name implies, are molds in which no sprues or runners are produced with the parts, although the tools do contain runner channels. The material being molded is kept in a plasticized state all the way from the heating cylinder of the injection molding machine to the gate into the mold cavity. Only molded parts are removed from the machine each time the mold opens.

Riteflex TPC-ET compounds have been successfully molded in many types of commercially available runnerless molds. Good molding practice calls for adequate temperature control of the runner system, which should have generously rounded bends to avoid resin hang-up. Other structural features where resin may hang up and degrade over time at elevated temperature should also be avoided.

4.2.6 Gates

Selection of appropriate gate geometry for molding Riteflex® TPC-ET depends more on the part than the resin. Various gate types are shown in Figures 4.2 and 4.3. Gate land area should be kept as short as possible (0.02-0.04 inch [0.5-1 mm]). The location of a gate should be chosen to achieve a flow pattern that will minimize anisotropic shrinkage and possibly cause distortion and warpage in the part. Ideally, the gate location will enable balanced flow in all directions while minimizing the flow length from the gate to the extremities of the part. If this cannot be done, the gate should be located so that the flow direction is along the axis of the most critical dimension. Various proprietary mold flow analysis software packages are available to model the effect of gate location.

4.2.7 Venting

The injection speeds achievable with Riteflex TPC-ET resins enable rapid mold filling. In such a circumstance, the air in the cavity can be rapidly compressed and thereby heated to a high temperature, causing burning along the flow front of the advancing polymer melt.

Adequate venting is needed to prevent this. The vent(s) should be located at the edge of the cavity furthest from the gates. The suggested vent size is 0.001 inch (0.025 mm) deep by 0.125 inch (3.2 mm) wide. Vents should be cut in the mold parting line from the edge of the cavity to the outside of the mold and should be deepened beginning 0.125 inch (3.2 mm) from the cavity. Proper venting is particularly critical at knit lines and in the lastfilled portion of the cavity.

4.2.8 Mold Cooling

Inadequate or poorly designed mold cooling can significantly affect machine productivity and part quality. The semi-crystalline nature of Riteflex TPC-ET resins enables them to solidify quickly from the melt, permitting achievement of fast cycle times. This requires a well-designed mold cooling system that provides a uniform temperature with cooling channels near thicker part sections, and (when possible) in mold insets and cores. Separate controllers for cavity and core are recommended for best results. (For specific designs, it may be advantageous to have the A and B parts of the mold at different temperatures, but this is not common.)

Fig. 4.2 • Various Gate Types Used in Injection Molds

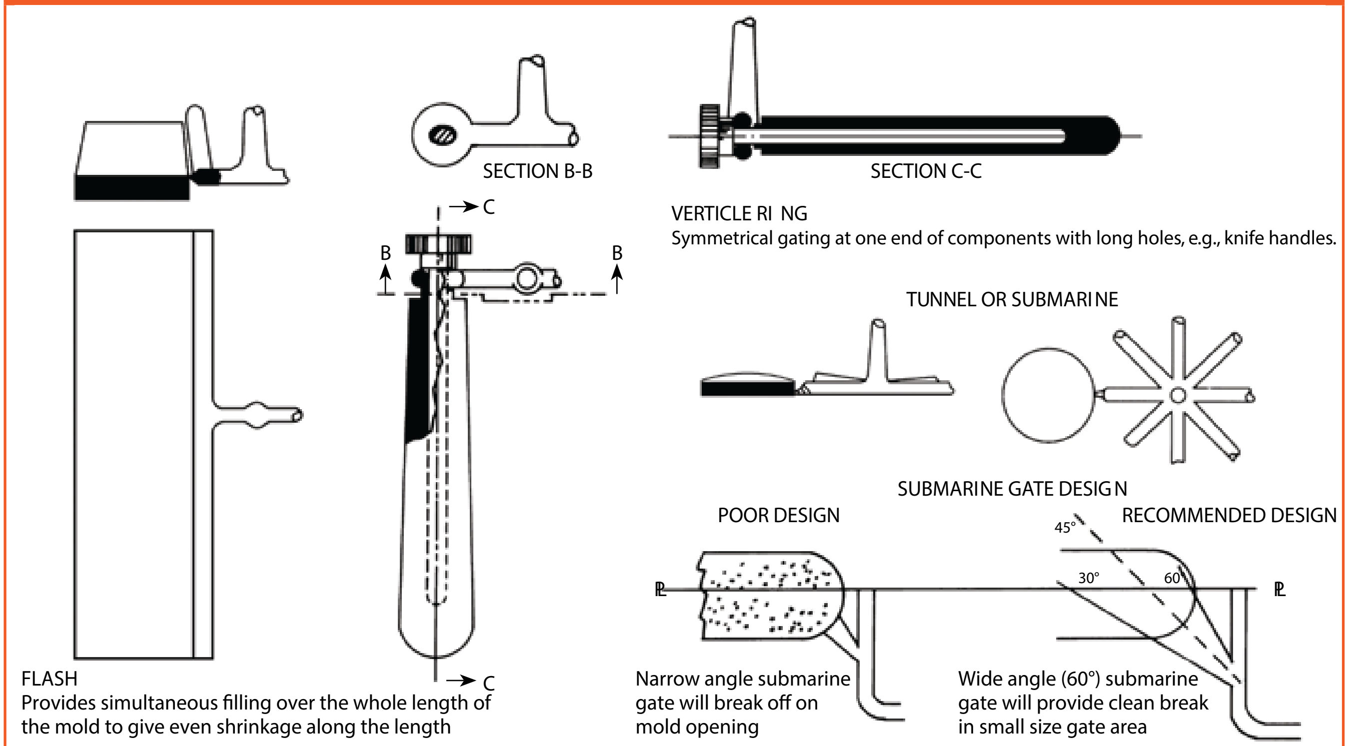
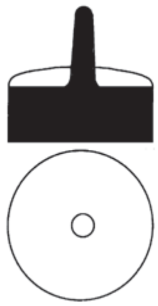
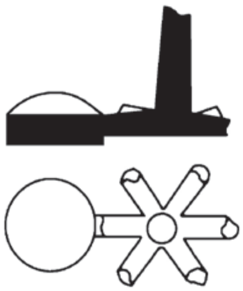


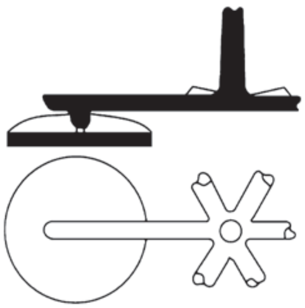
Fig. 4.3 • Various Gate Types Used in Injection Molds



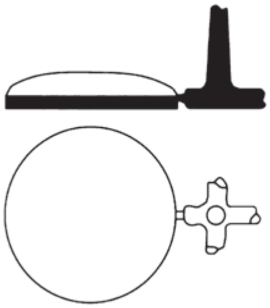
SPRUE: A simple design for single cavity molds and symmetry on circular shapes; suitable for thick sections



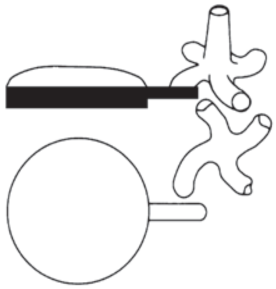
SIDE or EDGE: A simple design for multicavity molds. Suitable for medium and thick sections.



PIN (3 plate tool): Used to minimize finishing where edge gating is undesirable and for automatic degating; only suitable for thin sections

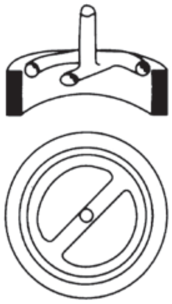


RESTRICTED or PIN: Provides simple degating and finishing; only suitable for thin sections



TAB: Used to stop jetting when other means are not available and when a restricted gate is desired; also enables area of greatest strain to be removed from the molding

DIAPHRAGM: Used for single cavity concentric moldings of ring shape with medium or small internal diameter



INTERNAL RING: Similar to diaphragm gate; used for molds with large internal diameters or to reduce (sprue/runner) to molding ratio

EXTERNAL RING: Used for multicavity concentric moldings of ring shape or where diaphragm gate cannot be used

5. Post-Processing

5.1 Assembly

Components molded of Riteflex® TPC-ET are easily assembled using conventional plastic joining techniques. In selecting the method for joining components, consideration must be given to:

- Specific part design to avoid surface damage to mating parts during the assembly process that could reduce mechanical properties such as impact strength or ultimate stress and elongation to break.
- Environmental conditions that the assembled part will be exposed to during its useful life.

5.1.1 Snap-fit Joints

A form-fitting snap-fit joint permits great design flexibility, but must be carefully planned, especially with the softer Riteflex TPC-ET grades, for which some joint designs may not be feasible. Some snap-fit joints are intended to become permanent assemblies, while others are intended for repeated assembly and disassembly. The three common types of snap-fit joints are barbed leg, cylindrical and ball and socket.

Barbed legs are cantilevered spring elements supported on one or both sides and are often used to attach a part through a hole in a mating part (see Figure 5.1). The hole can be rectangular, round or slotted. The cross section of the barbed leg is usually rectangular, but shapes based on round cross sections are also used. A cylindrical barbed-leg, snap-fit element is commonly divided by one or several slots to reduce assembly force. In designing a barbed-leg snap-fit element, take care to avoid over-stressing the root of the element, which is its most vulnerable point of support. For this reason, the radius "r" in Figure 5.1 should be as large as possible.

A cylindrical snap-fit element has a lip, or thick section at its nose (see Figure 5.2). This lip engages a corresponding groove (or hole) in the mating part. The difference between the largest diameter of the nose, DG, and the smallest diameter of the hole, DK, is the interference depth H. The parts are deformed by the amount of this interference depth during assembly

Fig. 5.1 • Barbed Leg Snap-fit

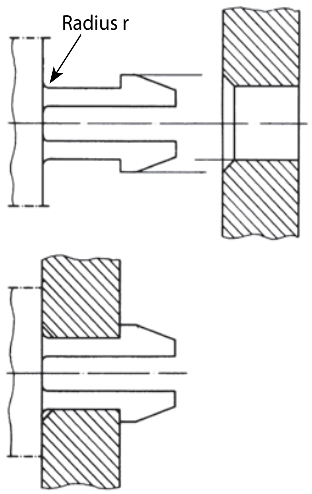
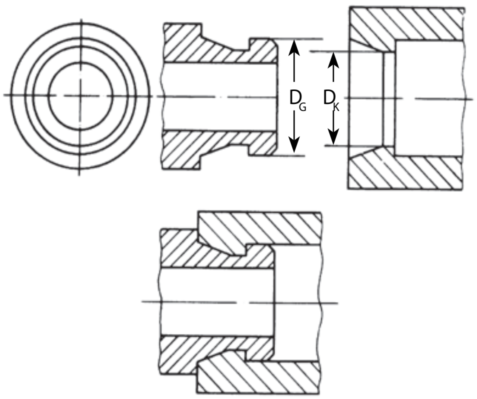


Fig. 5.2 • Cylindrical Snap-fit



Ball and socket snap-fits (see Figure 5.3) are mainly used where the joint is required to transmit motion. Here, a ball section engages a corresponding socket. The interference depth is the difference between the ball diameter, DG, and the diameter of the socket opening DK. The maximum permissible interference depth, Hmax, is given by Hmax = DG x Emax/100 where Emax is the maximum allowable elongation of the material.

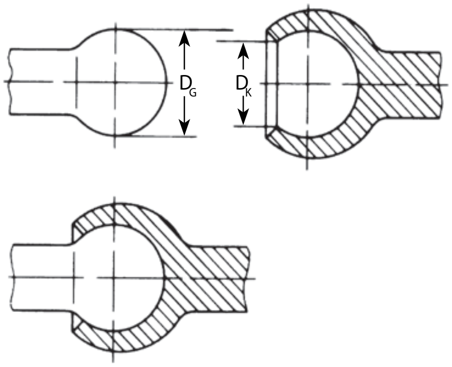
Regardless of the type of snap-fit, there is a linear relationship between undercut depth and hub elongation. For example, the maximum permissible undercut depth is limited by the maximum specified elongation. The load-carrying capacity of a snap-fit joint depends on the elastic modulus and coefficient of friction of the resin. It can be matched to the functional requirements of the joint by adjusting the undercut depth and the assembly retaining angle.

5.1.2 Strain Limits in Snap-fit Applications

Snap-fit joints tend to load parts in flexure, so it is best to use flexural strain data in design calculations. However, tensile data may also be used if that is all there is available. The following recommendations apply to grades of Riteflex® TPC-ET that exhibit defined yield points:

- If the flexural strain at break is less than 5.5%, then the maximum allowable strain should be 50% of the flexural break strain. If testing was stopped at 5.5% strain (as is generally the case in ISO testing) without showing a break, tensile test data may be used.
- The maximum allowable strain for materials with a clear tensile yield should be 70% of the yield strain for single snap applications and 40% of the yield strain for repeated snap use.
- If the material shows low elongation and breaks without showing a clear yield point, as may be the case in a special-purpose glass-reinforced formulation, the single-snap maximum strain should be 50% of the break strain and the multiple-use maximum strain should be 30% of the break strain.

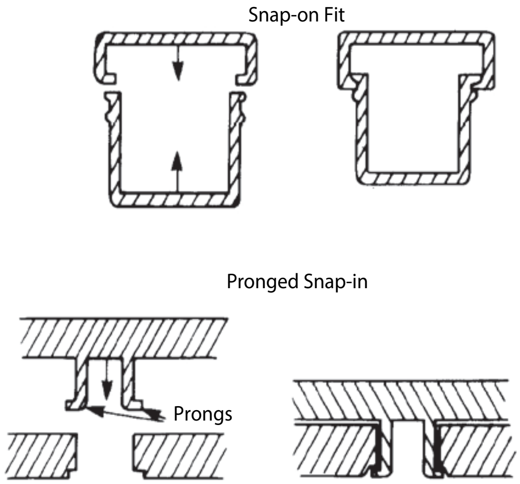
Fig. 5.3 • Ball and Socket Snap-fit



5.1.3 Snap-on/Snap-in Fits

As shown in Figure 5.4, this type of snap-fit can sometimes be molded into the part. The main advantage of this approach, which is most often used with rounded parts, is that some or all of the entire part flexes during the fitting operation, so that the actual local deflection is small and well below the yield strain. Snap-ons are also amenable to release of the assembled part by means of a special tool. This may occur when repeated servicing is needed of the operating equipment inside the plastic assembly.

Fig. 5.4 • Snap-on/Snap-in Fits



5.1.4 Self-Tapping Screws

Both thread-cutting and thread-forming screws may be used to join parts made from Riteflex® TPC-ET. Combinations of both designs may also be used and have the advantage of good holding power and minimized stress during thread forming. An appropriate pilot hole should be either molded in or drilled through the part before screw insertion. To maximize pull-out resistance, the pilot hole diameter should in general be slightly less than the screw diameter. As threads may not form adequately in softer grades of Riteflex TPC-ET and pull-out forces may be low, other methods of joining should be considered.

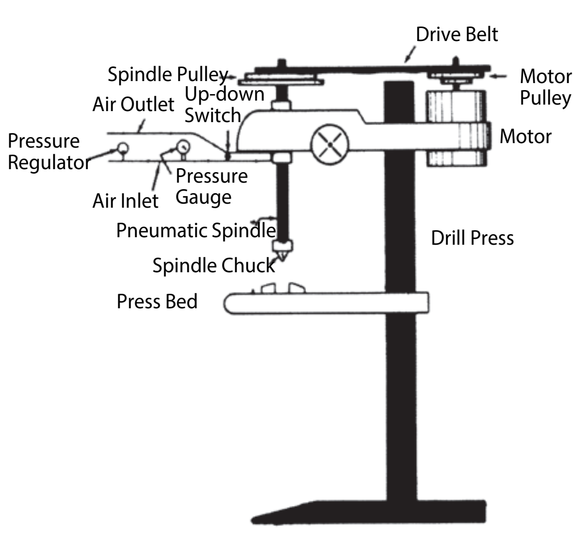
5.1.5 Threaded Metal Inserts

Where a screw connection is to be used, a threaded metal insert may give a stronger joint than a self-tapping screw. It is important to design the insert to minimize creation of molded-in stresses while maximizing pullout resistance. See paragraph 4.1.11 Molded-in Inserts for advice on knurling of inserts and avoidance of sharp corners and edges.

5.2 Welding Techniques

Most conventional plastic welding techniques may be successfully employed with Riteflex TPC-ET resis, including spin welding, thermal fusion or hot plate welding and ultrasonic welding.

Fig. 5.5 • Simple Spin Welding Apparatus



5.2.1 Spin Welding

Spin welding is a simple technique in which parts are bonded by a melt layer formed between them by the friction resulting from spinning one part against the other. While the weld produced is round, the parts may be of any shape. The equipment used may be very simple, or it can be made quite complex by the mechanical implementation of production requirements. Schematic drawings of a spin welding apparatus and driving tools are shown in Figures 5.5 through 5.7. Regardless of the complexity of the equipment, general operating principles for spin welding call for the stationary part to be positioned with the weld area in the same axis as the mating part. The positioning must allow the mating part to be brought down into firm contact with it. The raising and lowering mechanism should

Fig. 5.6 • Pivot Tool with Flash Trimmer

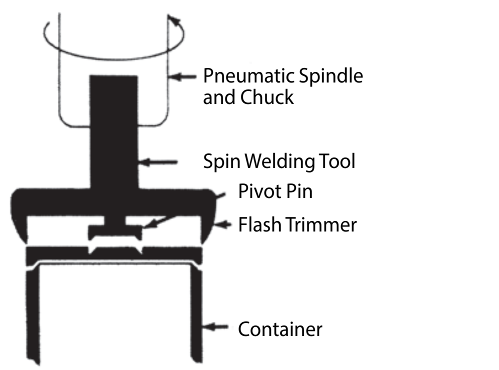
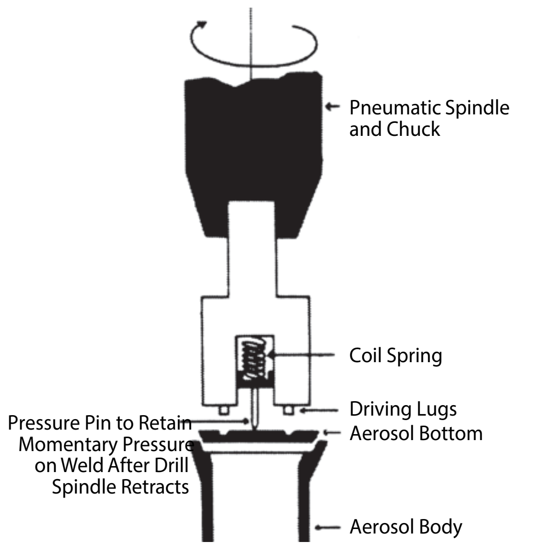


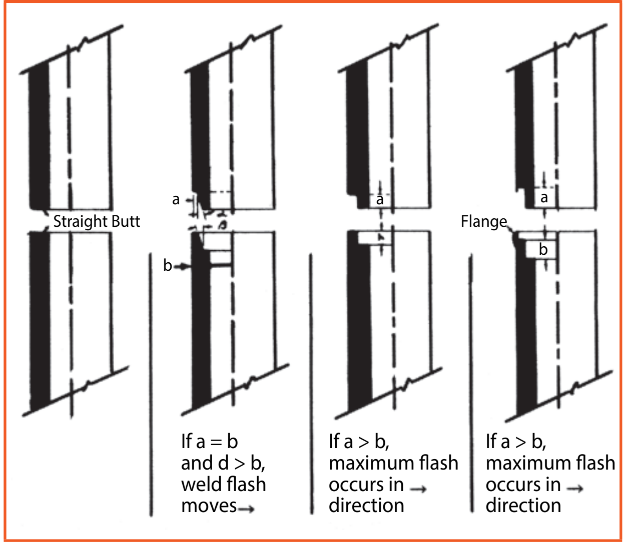
Fig. 5.7 • Driving Tools for Spin Welding



be checked for proper alignment before commencing spinning. As melting can be achieved in less than one second with proper alignment and contact pressure, it is important to stop spinning quickly and hold slightly greater pressure on the parts immediately thereafter.

Not all spin-welded joints need flat, 90° mating surfaces. Some joint surface may be angled, stepped or profiled. Examples of possible hollow structure joint configurations are shown in Figure 5.8. Angled or profiled joints can retain flash and provide added weld surface for greater strength.

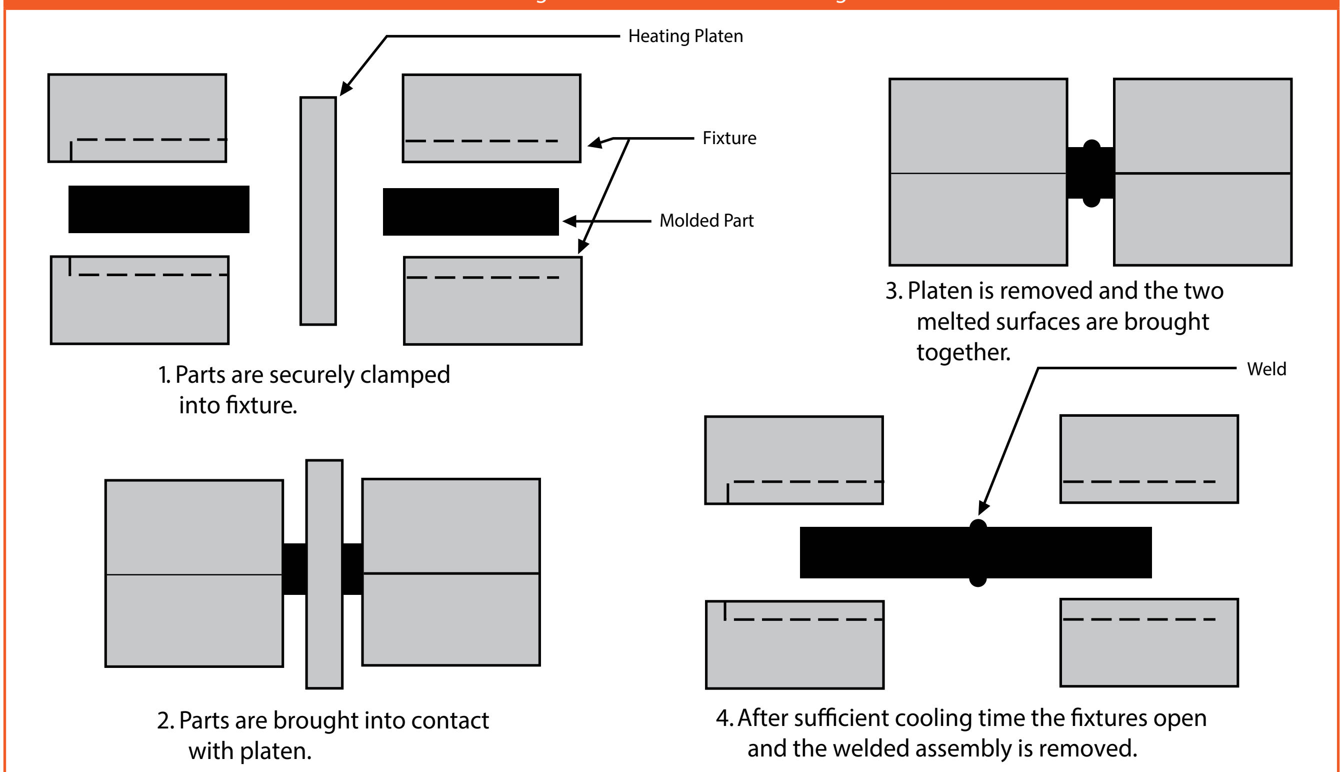
Fig. 5.8 • Typical Joint Configurations for Spin Welding (Hollow Members)



5.2.2 Thermal Fusion Welding

Also called hot-plate welding, this technique may be used for parts in a wide range of sizes. As shown in Figure 5.9, this process involves contacting the parts to be mated with a heated platen until melting occurs and then bringing the parts together under pressure until the melt solidifies. As in spin welding, equipment can range from a simple manual process to one that is complicated and automated.

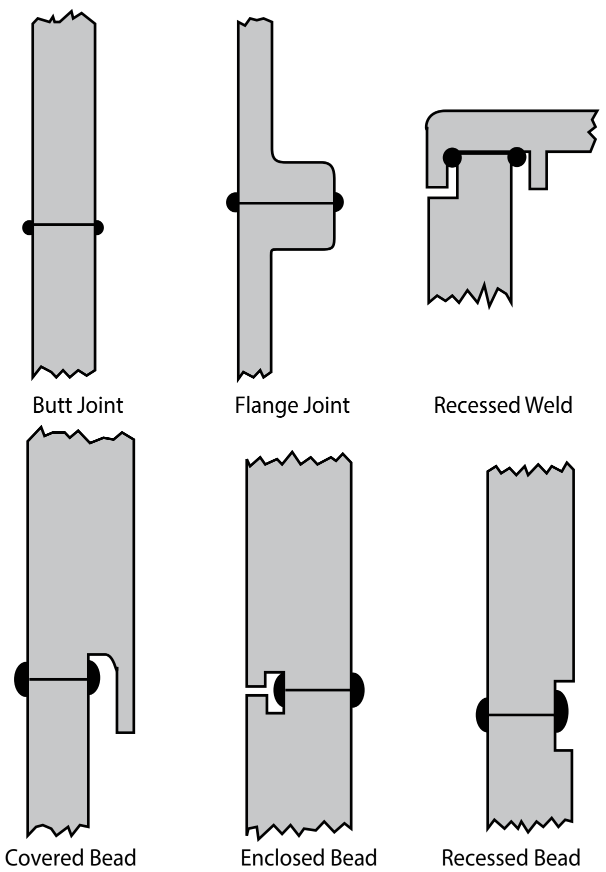
Fig. 5.9 • Thermal Fusion Welding



Thermal-fusion welding generates flash at the joint line, and flash removal by special equipment or concealment by joint design may be necessary. Figure 5.10 shows some typical joint designs, including several indicating how flash may be concealed. If a flash trap is to be used, sufficient volume for flash collection should be provided. The amount of material to be displaced by the joint must be decided during initial part design and adequate allowance made to achieve the desired dimensions. Generally, about 0.02 inch (0.5 mm) per side of displacement may be expected. The mating part surfaces should be flat, clean of foreign material and dry.

Achieving rapid welding cycles depends on rapidly heating the resin, a process that is determined by the material's thermal conductivity. The heating platens should therefore be as hot as possible to achieve a sufficient melt depth without degrading the contact surface. Parts should be placed in contact with the hot platen under light pressure, usually 14-34 kPa (2-5 psi) measured across the joint area. Excessive pressure may

Fig. 5.10 • Typical Thermal Fusion Weld Joint Designs



cause molten polymer to flow out from the joint area, reducing heating efficiency and creating excessive flash. Travel of the welding equipment should allow approximately 0.01 inch (0.3 mm) of resin displacement before being halted by a positive stop. Contact should be maintained until a further 0.12-0.18 inch (0.3-0.5 mm) of melting has occurred. The parts are then pulled back from the platen, which is removed to enable the parts to be brought together as quickly as possible. These steps are shown schematically in Figure 5.11.

Although Riteflex® TPC-ET resins have lower levels of crystallinity than other polyester materials, they do exhibit relatively sharp crystalline and freezing/melting points so that the distances moved and the time required should be kept as short as possible to achieve the best weld strength. Under optimal conditions, about 2/3 of the molten resin should flow from the joint, i.e., 0.1 inch (0.3 mm) when plasticized to a depth of 0.015 inch (0.4 mm). As the weld cools, a holding pressure of 15-35 psi (100-140 kPa) is generally acceptable.

5.2.3 Ultrasonic Welding

This quick and economical joining method gives good results when joining parts made from chemically compatible materials with similar or equivalent melting characteristics. As shown in Figure 5.12, a typical ultrasonic welding unit provides for generation and control of high frequency vibrational energy and its delivery to the mating part via a horn. Frequencies used are approximately 20 kHz for most parts, with 40 kHz being used for small, delicate parts.

The process involves vibrating the mating part against the stationary part, typically over a small area, to very quickly produce melting. The melt area is extended as the parts are telescoped together by the welding unit, creating a strong bond. A shear joint, as shown in Figure 5.13, is the preferred way to achieve a melt interface that completely fills the space between the mating surfaces. To obtain satisfactory high-quality welded joints, consider the following factors:

- Initial contact between the mating surfaces should be small to concentrate the applied energy and decrease the time and total energy needed. In some cases, the ultrasonic energy should be applied prior to part contact in order to avoid fracture. 39

Fig. 5.11 • Heating the Plastic Resin for Welding

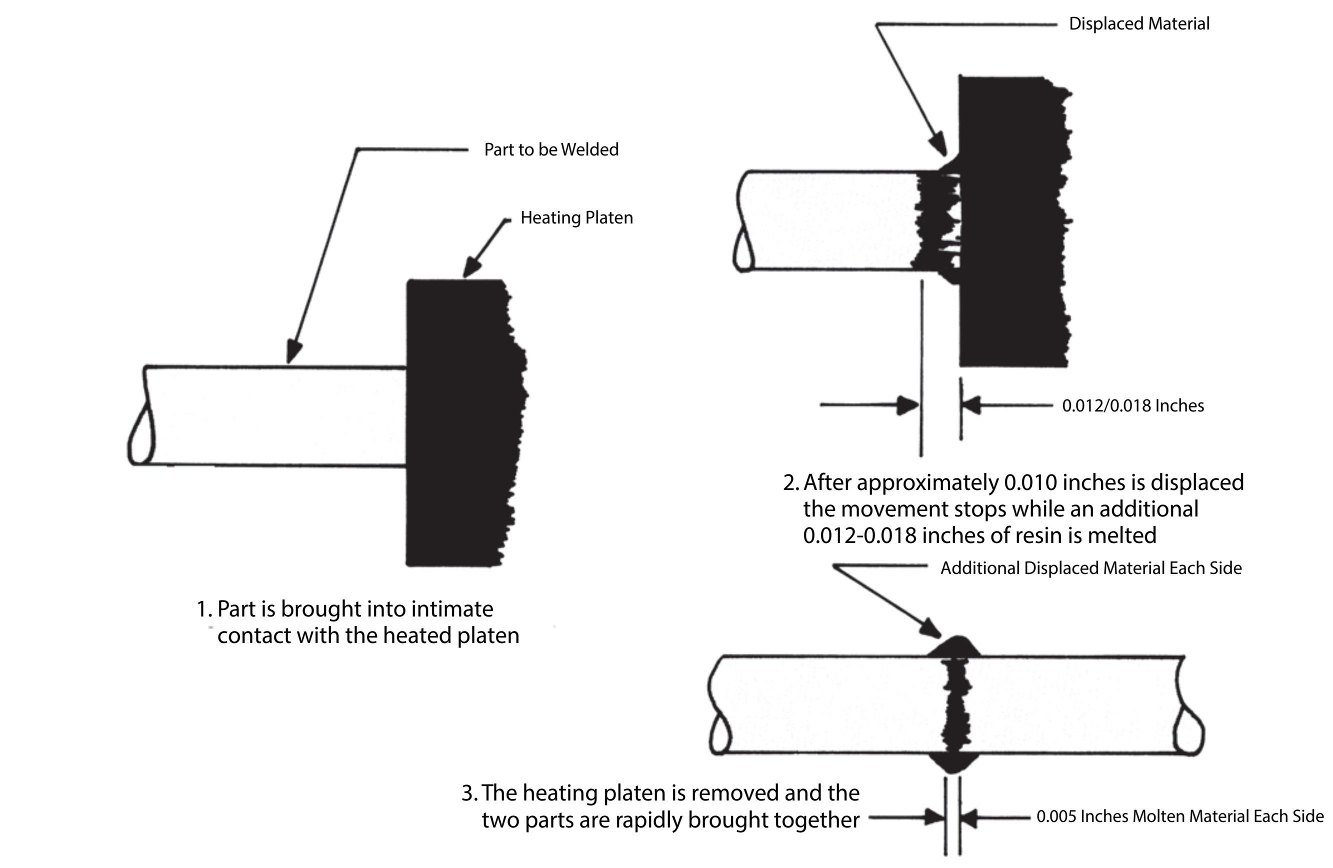


Fig. 5.12 • Typical Ultrasonic Welding Equipment

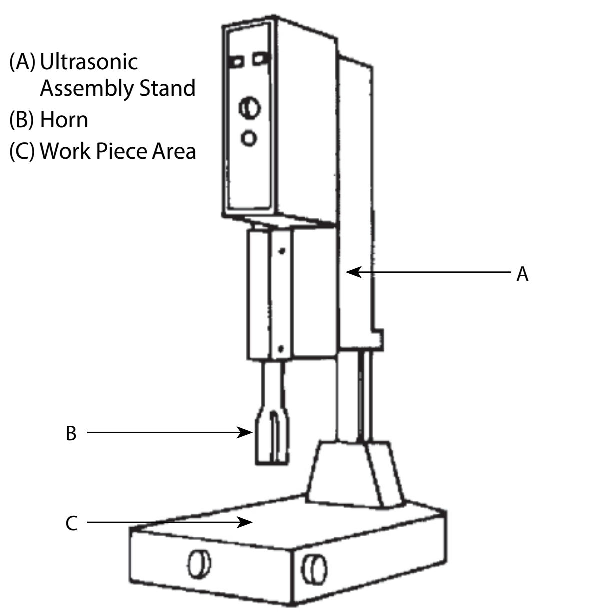
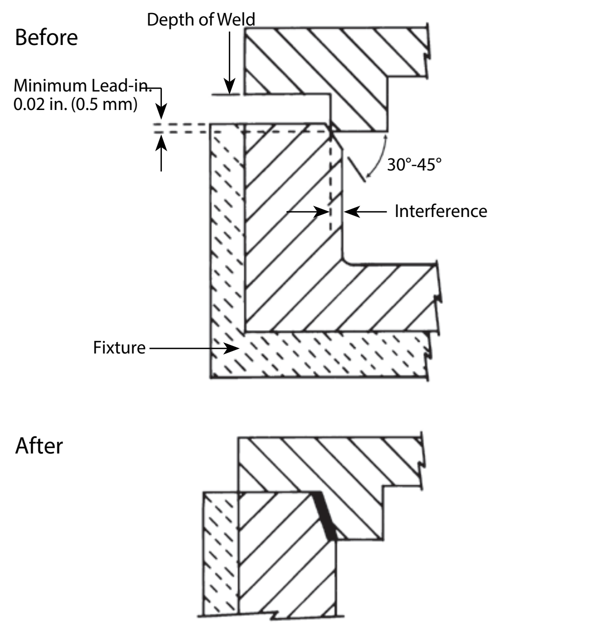


Fig. 5.13 • Recommended Shear Joint Configuration



- Mating surfaces surrounding the entire joint interface should be uniform and in intimate contact with each other. If possible the joint area should be all in one plane.

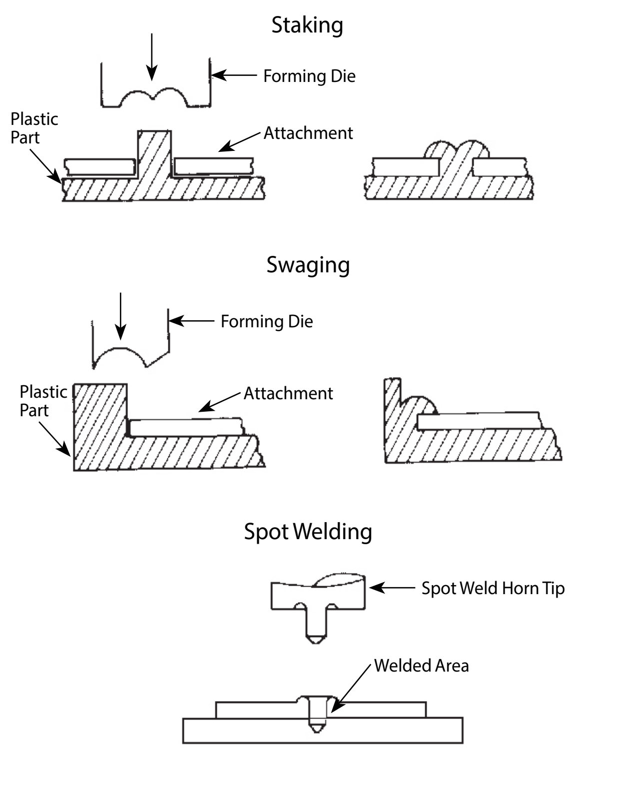
- Mating parts must be well designed, molded to dimension and precisely aligned. Use support fixtures, pins and sockets, tongues and grooves or other features to hold parts in place. Do not rely on pressure from the horn for this purpose.

- Make sure that the mating surfaces are clean and dry.

- Holes and other openings in the mating surfaces should be avoided because they can interrupt energy transmission and compromise the weld integrity. For the same reason, bosses or other projecting surfaces on the part surface should be well radiused to avoid fracture due to mechanical vibration.

Bowing of flat circular parts may sometimes occur during ultrasonic welding. This can usually be eliminated by increasing wall thickness or by adding internal support ribs. Minimizing weld time may also help.

Fig. 5.14 • Ultrasonic Staking, Swaging and Spot Welding



For ultrasonic welding as for all welding processes where polymeric materials are melted, adequate ventilation should be provided at the welding station(s) to remove any fumes generated during processing.

Ultrasonic energy applications are not limited only to part welding. As shown in Figure 5.14, this technique may also be employed for staking, swaging and spot welding. In each case, the ultrasonic horn is provided with an appropriately shaped forming die or tip. These methods of attachment also have the advantage of very short cycle times, capability to handle tight asse bility to perform multiple operations with one machine. A further use of the technology is for driving of metal inserts into the plastic parts for subsequent mechanical assembly.

5.2.4 Adhesive Bonding

Parts molded from Riteflex® TPC-ET may be bonded to each other or to dissimilar materials with commercially available adhesives. Though such bonds will not in general be as strong as those obtainable by welding, they can be quite satisfactory, especially where the bond area is large. Due to the good chemical resistance of Riteflex TPC-ET, which inhibits attack by most solvents, mechanical roughening of the surfaces to be joined is required. The mating surfaces should be sanded and cleaned with a solvent such as, e.g., acetone, before applying the adhesive. The surfaces should be closely mated so that the adhesive layer is thin. Common adhesives that may be used to bond Riteflex TPC-ET include cyanoacrylates, methacrylates, epoxies and polyurethanes. When using any such adhesive system, be sure to read and follow the use instructions and safety precautions provided by the manufacturer.

5.3 Mechanical Processing

Parts made from Riteflex TPC-ET may be finished by most conventional processes, subject to a few limitations on mechanical processing of the softer grades. Machining, sawing, drilling, turning, milling and similar operations may all be accomplished on standard equipment with appropriate procedures as described below.

5.3.1 Machining

- Use only sharp tools
- Provide adequate chip clearance
- Support the work properly, especially for softer grades
- Provide adequate cooling, especially for softer grades

5.3.2 Sawing

- Use sharp-tooth blade with adequate offset to prevent binding
- Use a coarse-toothed blade, such as for example 6 tpi, rather than a fine-toothed one
- For smoother cuts, run at high speed
- Use extra wide gullets for chip clearance
- For sections less than 0.5 inch (12.7 mm), cool the cutting area with air, water or oil
- Back up thin sections with cardboard or chipboard
- For sections thicker than 0.5 inch (12.7 mm) use water cooling on the cutting area
- For softer grades, cool the surface with air, water or oil
- Once a cut is started, it may be necessary to hold it open

5.3.3 Drilling

- Run at 1000-3000 rpm and feed as fast as possible. Excessive rpm will melt the plastic
- Support the workpiece firmly during drilling
- Clear deep holes frequently – every 0.25 inch (6.4 mm) of bit travel
- Cool with an air jet or water-based coolant aimed into the hole
- For softer grades using oversized bits at low rpm may help maintain tolerances
- For softer grades using undersized bits at high rpm may help maintain tolerances
- Drill test holes at the intended speed to determine the right bit size for target diameter

5.3.4 Turning

- In general, feeds and speeds depend on the nature of the cut and finish desired
- Rough cuts at 1500-2500 rpm with feeds of 20 in/min (51 cm/min) may cause stringing
- Faster speeds may give a better finish, but cooling may be required
- Keep cutting tools well sharpened
- Allow enough clearance to avoid overheating the workpiece

5.3.5 Milling

- Keep the flute count as low as possible (2-4) to minimize overheating the workpiece
- Run cutter at 2000-4000 rpm and feed as fast as possible consistent with surface finish
- Use an air-jet to keep flutes from clogging

5.3.6 Rotary Power Filing

- For better chip clearance, use ground burrs rather than hand-cut rotary files
- Use high-speed steel burrs (medium cut) or carbide burrs (medium or diamond cut)
- Operate steel burrs at 800-1000 surface fpm and carbide burrs at around 2000 fpm

5.4 Surface Treatment

A variety of surface treatments may be used with Riteflex® TPC-ET grades, including dyeing, painting, hot stamping, in-mold decorating and laser marking. Sublimation printing may yield faded colors and diffused images, especially with the softer grades.

5.4.1 Painting

Painting may be done with commercially available coating systems. Bake temperatures should be adjusted downward for the softer grades. Further shrinkage or warpage may occur during baking. Coating systems typically employ a primer and a topcoat, which may be specified by the end-user, particularly in automotive applications. In such a case, contact the end-user or Celanese for detailed information.

5.4.2 Hot Stamping

The hot stamping process uses a wide range of foils with pigmented and/or metallized coatings, and provides high-gloss, semi-gloss or matte finishes. The choice of foil must match both the aesthetic and functional requirements of the application and be processable onto the specific grade of Riteflex® TPC-ET. Each application should therefore be discussed with the foil manufacturer to ensure that the final product meets the end-use requirements. Foils, films and labels may also be applied by in-mold decorating. In such cases, part geometry must be fairly simple and molding cycles may be somewhat lengthened.

5.4.3 Printing

Various printing methods can be used to apply graphics, serial numbers, bar codes and the like to Riteflex TPCET parts. These methods include offset printing, silk screening, pad printing, sublimation printing and laser marking. However, sublimation inks may continue to diffuse through the TPC-ET material, especially thesofter grades, so image longevity with this method should be verified prior to production printing.

5.4.4 Laser Marking

Laser marking can be used to produce graphics to a depth of several thousandths of an inch without using inks, dyes or paints. This method is well adapted to matte or high-gloss finishes and to flat or curved parts. White markings can be placed on dark surfaces and vice versa. Both neodymium:yttrium aluminum garnet (Nd:YAG) and excimer lasers have been used, the latter for making dark marks on white parts.

5.4.5 Sterilization

Standard sterilization processes such as gamma radiation, ethylene oxide and steam autoclave may be used with Riteflex TPC-ET resins subject to limitations on the use of steam sterilization with softer grades of the material. As shown in the table below presenting thermal property data from Section 2.3, exposure of mechanically loaded parts to autoclave temperatures may cause deformation. Grades 425 and 435 may soften and sag in the autoclave and should not be subjected to steam sterilization.

Table 5.1 • Thermal Properties of Riteflex TPC-ET Resins

		Riteflex Thermoplastic Polyester Elastomers								
	Units	425	435	440	447	640A	655A	663	672	677
Heat deflection temperature, 0.45 MPa	°C	42	45	47	60	56	75	114	118	109
Vicat softening temperature, 10N, 50°C/hr	°C	61	122	127	—	119	176	194	205	213

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- Celstran,® Compel® and Factor® long fiber reinforced thermoplastic (LFRT)
- Celstran® continuous fiber reinforced thermoplastic (CFR-TP)
- Fortron® polyphenylene sulfide (PPS)
- GUR® ultra-high molecular weight polyethylene (UHMW-PE)
- Impet® thermoplastic polyester (PET)
- Riteflex® thermoplastic polyester elastomer (TPC-ET)
- Thermx® polycyclohexylene-dimethylene terephthalate (PCT)
- Vandar® thermoplastic polyester alloy (PBT)
- Vectra® and Zenite® liquid crystal polymer (LCP)

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