Celanese
The chemistry inside innovation™

Polyester Products

Celanex® PBT
Impet® PET
Vandar® PBT

Polyester Technical Manual

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Oven handles maintain gloss and color even under high heat exposure with little or no blooming.

Outstanding high crystallinity makes Celanex® PBT 2008 good for use in meltblown nonwovens with very fine structures, such as laminated fuel filter media.

Properties

Inhalers for asthma sufferers – Complex mechanics ensure optimum safety and precision. The components are made of Hostaform® POM and Celanex® PBT.

Processing

Celanex® XFR® PBT meets international halogen-free, V-0 standards.

Part and Mold Design

Appearance grades, such as metallic-effect PBT, add style and functionality to applications.

Post-Processing

1 2 3 4 5

1. Overview

1.1 Product Description

Thermoplastic polyesters are among the most important of engineering resins. They combine a wide range of desirable physical, mechanical and electrical properties with excellent chemical and environmental resistance. Polyester materials can be found in almost every application area calling for reliable and predictable engineering properties. Celanese plays a leading role in product and application development of thermoplastic polyesters and offers a broad product portfolio backed by deep experience. Celanese's polyester product lineup includes Celanex® polybutylene terephthalate (PBT), Impet® polyethylene terephthalate (PET) and Vandar® polyester alloys (PBT). Celanese also offers Riteflex® thermoplastic polyester elastomers (TPC-ETs). A comprehensive technical manual, TPE-001, is available separately for these materials.

The basic PBT and PET polymers in Celanese's polyester products are strong, stiff, semi-crystalline materials. They deliver good surface hardness and excellent resistance to many organic and inorganic chemicals, particularly those found in the automotive underhood environment. Building on these basic strengths, Celanese engineered a comprehensive product family including numerous polymer variants, reinforced and filled grades covering the practical range of compositions, and impact-modified compounds. Flame-retarded products are also available in both Celanex PBT and Vandar PBT alloy product families. The desirable attributes of Celanese's thermoplastic polyesters provide many application benefits including:

- High strength, stiffness and toughness to perform in mechanically demanding applications
- Low creep to retain key dimensions over time, even well above room temperature
- High temperature resistance to withstand long-term exposure to hot environments
- Minimal moisture absorption for dimensional stability under high humidity
- Superior chemical resistance to tolerate exposure to chemicals and solvents, oils and greases
- Easy colorability and good surface gloss for attractive aesthetics in appearance parts
- Alloying compatibility to enable creation of highly flexible, high impact products

The thermoplastic polyesters can perform over a broad temperature range, going from grades having impact resistance down to -40°C (-40°F) to those with deflection temperatures under load above 200°C (392°F). Being excellent insulators, they have superior electrical properties with high dielectric resistance and low dielectric loss. High crystallinity and low moisture absorption provide parts with good dimensional stability and high creep resistance, even at higher temperatures.

While the three product families share the advantages provided by their basic polyester chemistry, each has its own functional focus:

- The Celanex PBT product family has the broadest product line and widest extent of uses, going from tiny watch parts to large automotive body components and from injection molding to extrusion and blow molding. It provides an extremely capable range of engineering materials.
- Impet PET products are targeted to injection molding applications and offer somewhat higher mechanical properties than those of their Celanex PBT counterparts. The higher melting point of the base polymer also enables these resins to withstand higher temperature exposures. To meet industry requirements for recycle content, certain Impet PET grades are available with a minimum level of 25% recycled polymer.
- Vandar PBT alloy resins are much tougher and more flexible than the other products, and have high practical impact down to very low temperatures, while still retaining functional stiffness at higher temperatures. These attributes have won them important automotive applications, particularly in the area of safety.

Celanese's polyesters can be colored to match almost any specification. A wide spectrum of standard and custom colors is available, including numerous automotive standard colors. Many code and agency approvals and ratings are also available for the various members of this adaptable product family, including those of Underwriters Laboratories (UL), the National Sanitation Foundation (NSF), the Canadian Standards Agency (CSA) and the US Food and Drug Administration (FDA). Celanese's polyester resins also meet the requirements of many DIN and ISO standards, and certification to relevant military specifications is available for certain grades.

Conventional thermoplastics processing methods, particularly injection molding and extrusion, may be used with Celanese's thermoplastic polyester materials. Processing temperatures range between about 230°C and 300°C (446°F and 572°F), depending on the specific process and the grade chosen. Good thermal stability and low melt viscosity make for easy processing and fast molding cycles. Special extrusion grades are available to meet the needs of very specific end-use applications. All grades should be appropriately predried prior to melt processing. In every case, the appropriate Material Safety Data Sheet (MSDS) should be consulted before processing any Celanex® PBT, Impet® PET or Vandar® PBT alloy resin.

1.1.1 Crystallinity

Polyester polymers can be processed to have high crystallinity – typically as high as 60% – giving them such useful properties as high hardness, stiffness, strength and chemical resistance. PBT polymers exhibit almost instantaneous crystallization from the melt, enabling them, and compounds based on them, to be molded with short cycles in cooler tooling. The immediate high crystallinity also contributes to reduced post-molding shrinkage, thereby enhancing dimensional stability.

As the crystallization rate of PET polymers is temperature dependent, fully crystalline parts are obtained in faster cycles with warmer molds. Overly cool tooling may inhibit full development of crystallinity and should therefore be avoided.

1.2 Available Grades

The extensive array of desirable properties provided by Celanese's polyester resins derives from nearly 50 years' experience in developing and manufacturing polyester polymers. This fundamental competency has been augmented with a background in polyester compound technology extending from Celanese's launch of the first commercial PBT resin in 1970 up to the present day. As shown in Figure 1.1, these skills interact constructively with each other to yield the whole range of thermoplastic polyester products. As well as the compositions described above, Celanese's polyester materials can incorporate additives to enhance mold release, increase resistance to ultraviolet (UV) radiation, facilitate laser marking and increase thermal and hydrolysis resistance. A full range of colors is also available. Table 1.1 lists available grades by product family, type, grade and description.

Figure 1.1 • Polyester Product Relationships

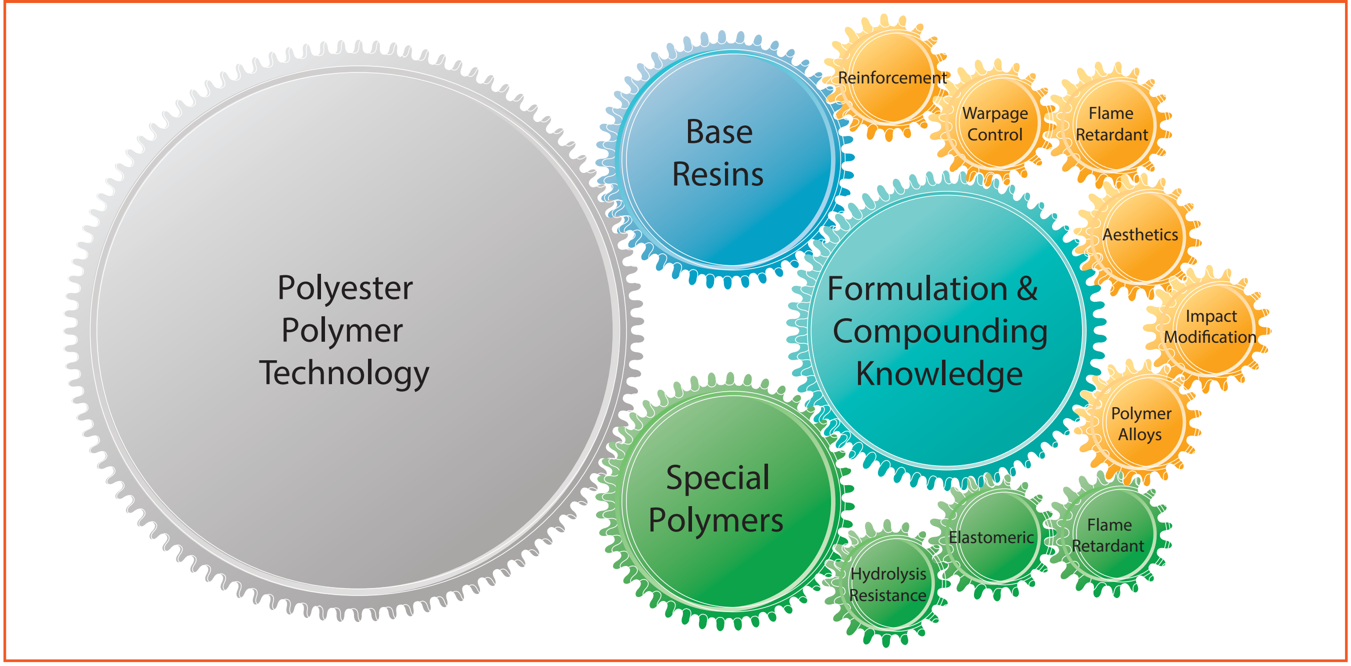

Table 1.1 • Available Polyester Grades

Product	Description
Celanex® PBT	
Unreinforced	
1400A	General purpose, high flow
1600A	Extrusion grade, standard flow
1700A	Extrusion grade, high viscosity
2001	Extrusion grade, standard flow, hydrolysis restraint
2002-2	General purpose, standard flow, high-gloss appearance
2008	Meltblown grade, ultrahigh flow
2025	Specialty grade, ultrahigh flow, high melt point
2401MT	Medical technology grade, standard flow
2402MT	Medical technology grade, standard flow, fast cycling
2403MT	Medical technology grade, high flow fast cycling
2404MT	Medical technology grade, standard flow, low wear
Glass Reinforced	
3100-2 7.5%	Glass reinforced
3200/3200-2	15% Glass reinforced
3202 20%	Glass reinforced
3300/3300-2	20% Glass reinforced
3400-2 40%	Glass reinforced
Glass Reinforced Improved Impact	
4202 15%	Glass reinforced
4300 30%	Glass reinforced
4302 30%	Glass reinforced, lower warpage
Flame Retardant	
2016	Unfilled, high flow
3116 7.5%	Glass reinforced
3216 15%	Glass reinforced, high flow
3226 20%	Glass reinforced, high flow
3314 30%	Glass reinforced
3316 30%	Glass reinforced, high flow
4016	Unfilled, high flow, improved toughness
7716 35%	filled/reinforced, low warp, high flow
XFR 6842 GF30	30% Glass reinforced, non-halogenated
XFR 6842 GF20	20% Glass reinforced, non-halogenated
XFR 6842 GF15	15% Glass reinforced, non-halogenated
XFR 6842 GF10	10% Glass reinforced, non-halogenated
XFR 4840	Unfilled, non-halogenated

Table 1.1 • Available Polyester Grades

Product	Description
Celanex® PBT	
Glass Reinforced Surface Finish	
5202	15% Glass reinforced
5202HF	15% Glass reinforced, high flow
5205HG	15% Glass reinforced, super high gloss, gas assist/injection molding
5214HF	15% Glass reinforced, flame retardant
5300	30% Glass reinforced
5314	30% Glass reinforced, flame retardant
Glass/Mineral	
J600	40% filled/reinforced
6200	15% filled/reinforced
6402R	40% filled/reinforced with 25% post-consumer recycle content
6407	30% filled/reinforced
6500	30% filled/reinforced, higher strength
6500HF	30% filled/reinforced, higher strength, high flow
Hydrolysis Resistance	
2003	HR Unreinforced
3209	HR 15% Glass reinforced
3309	HR 30% Glass reinforced
3309	HRHF 30% Glass reinforced, high flow
3309	HRT 30% Glass reinforced, improved toughness
3316	HR 30% Glass reinforced, V-0
3425	HRT 40% Glass reinforced, improved toughness, high flow
4309AR	30% Hydrolysis- and alkaline-resistant
JKX-1153	30% Filled/reinforced, high flow
Laser Markable	
3300LM	30% Glass reinforced
6500LM	30% Filled/reinforced, higher strength
J600LM	40% Filled/reinforced
Heat Shock	
4302HS	30% Glass reinforced, low warp
531HS	30% Glass reinforced
Other Special	
6035GB20	20% Glass bead
6035UVGB20	20% Glass bead, UV resistance
LW2333R	50% Glass reinforced, low warp

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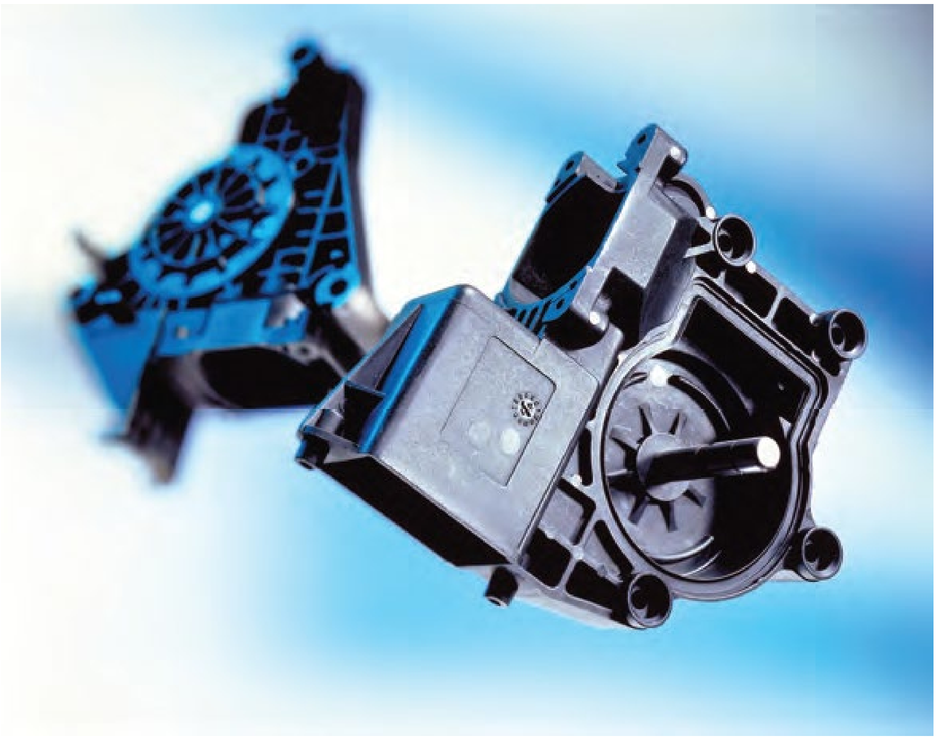
Table 1.1 • Available Polyester Grades

Product	Description
Impet® PET	
Glass Reinforced	
330R	30% Glass Reinforced (≥25% post-consumer recycle content)
340R	45% Glass Reinforced (≥25% post-consumer recycle content)
830R	35% filled/reinforced (≥25% post-consumer recycle content)
2700 GV1/20	20% Glass reinforced (Europe)
2700 GV1/30	30% Glass reinforced (Europe)
2700 GV1/45	45% Glass reinforced (Europe)

Table 1.1 • Available Polyester Grades

Product	Description
Vandar® PBT Alloys	
Unreinforced	
2100	General purpose, low-temperature impact, paintable, printable
2500	General purpose, good colorability, paintable
4602Z	General purpose, good chemical resistance, weather resistance
6000	Good low-temperature impact, low shrinkage
8000	Flame retardant
Glass Reinforced General Purpose	
4361	30% Glass reinforced, improved toughness
4612R	7% Glass reinforced
4632Z	15% Glass reinforced
4662Z	30% Glass reinforced

Drive housing for electric window lifters – Celanex® PBT 20% GF lends itself well to this application because of its good heat resistance, toughness and easy processing.



1.2.1 Applications

The extensive range of properties and easy processing offered by Celanese's polyester resins enables them to serve a highly diverse spectrum of engineering applications distributed across many markets. Table 1.2 lists some examples of these applications by product family and type.

Table 1.2 • Some Applications for Polyester Materials

Product	Description
Celanese® PBT	
Unreinforced	Monofilament, Films, Fibers, Cable Jacketing, Coatings, Netting, Keycaps, Fiber Optic Buffer Tubes, Paint Brush Bristles, Hot-Melt Adhesives, Performance Additive (for Fibers/Films), Oil/Fuel Filtration, Blood Filtration, Binder Fiber for Headliners and Hoodliners, Non-Woven Filter Media, Hinged Connectors, Appearance Parts
Glass Reinforced	Motor Housings; Automotive Underhood, Interior and Exterior Components; Coil Bobbins and Cases; Connectors, Sensors, Switches, Relays; Appliance Housings, Hardware, Vents and Trim
Glass Reinforced Improved Impact	Pump Housings and Impellers, Power Tool Components, Connectors with Snap-Fits
Flame Retardant	Connectors, DIP Sockets, Motor Components, Stator Insulation, Bobbins, Switches, Brush Holders, CRT Sockets, Terminal Boards, Lighting
Glass Reinforced Surface Finish	Appliance Housings, Handles and Bases, Oven Handles
Glass/Mineral Low Warp	Fan Blades, Shrouds and Housings; Electrical Housings; Air Mass Flow Sensors, Automotive HVAC Veins
Hydrolysis Resistance	Automotive Connectors and Sensor Housings, Automotive Under-Hood Components
Laser Markable	Components Requiring Indelible Markings for Identification and Traceability
Heat Shock	Pencil Coil, Other Ignition System Components, Sealed Connectors, Housings with Metal Inserts
Metallic Effects	Appliance, Pool and Spa, Kitchen and Bath, Automotive, Hand Tools, Knobs, Buttons and Trim
Other Special	Automotive Seat Belt Latch Covers, Coat Hooks, Interior Door Handles
Impet® PET	
Glass Reinforced General Purpose	Windshield Wiper Brackets, Heater and Air Conditioning, Doors and Vents, Rigid Parts Requiring Use of Recycle
Low Warp General Purpose	Grille Opening Panels and Retainers, Throttle Body Covers, Rigid Parts Requiring Recycle Content
Vandar® PBT Alloy	
High Flexibility	Air Bag Covers, Ski Bindings, Conveyor Element Linkage, Protective Equipment, Clips and Fasteners, Reusable Dunnage
Reinforced/ General Purpose	Telephone Line Splice Cases, Small-Appliance Housings, Power Tool Housings

1.3 Regulatory/Agency Compliance

Not all grades are covered by all regulatory codes and agencies. Call Product Information Services at 1-800-833-4882 for current information. Celanese's polyester resins are in compliance with or have ratings under the standards of many regulatory codes and agencies including:

- Underwriters Laboratories (UL)
- United States Food and Drug Administration (FDA)
- United States Pharmacopoeia (USP)
- Canadian Standards Association (CSA)
- National Sanitation Foundation (NSF)
- United States Department of Transportation (USDOT)
- Military Specifications (MIL-Spec)
- American Society for Testing and Materials (ASTM)
- EU Restricted Hazardous Substance (RoHS)
- Waste Electrical and Electronic Equipment Directive (WEEE)

1.3.1 UL

Most major polyester formulations have UL recognition covering electrical, mechanical and thermal characteristics. The ratings apply to burning behavior as a function of part thickness and to relative thermal indices for electrical properties, mechanical properties with impact and mechanical properties without impact. In general, Celanese's polyester products other than those specifically rated V-0 are rated HB on burning behavior in the UL-94 test. Depending on the specific grade, electrical and mechanical relative thermal index (RTI) ratings range from a low of 75ºC (167ºF) to highs of 140ºC (284ºF) for mechanical and 150ºC (302ºF) for electrical properties. These ratings are published under UL's yellow card system.

Yellow cards are readily available detailing UL recognition of Celanex® PBT, Impet® PET and Vandar® PBT alloy products. See Table 2.1 in Chapter 2 for UL-94 and RTI ratings by product grade. UL approvals have also been granted for the use of many grades of Celanex PBT in certain bobbin insulation systems under File No. E60824. Information from this file can be released to customers by UL on request from Celanese. See Table 1.3 for a list of grades with bobbin approval.

1.3.2 FDA – Food Contact

Many Celanese polyester grades are compliant for food contact according to USA FDA and EU food contact regulations.

Natural Celanex PBT grades designated "MT®" comply with the requirements of FDA regulation 21 CFR177.1660 and applicable EU regulations for use in food contact applications. See Table 1.3 for a list of other compliant grades.

1.3.3 FDA – Drug Master File

All MT grades of Celanex® PBT natural are listed in Celanese's FDA Drug Master File (DMF) #10047.

1.3.4 FDA – Device Master File

All MT grades of Celanex PBT are listed in Celanese's FDA Device Master File (MAF) #1078.

1.3.5 USP

Celanex PBT grades designated "MT®" meet the requirements of USP Class VI and ISO 10993. See Table 1.3 for other compliant grades.

1.3.6 CSA

Many of Celanese's polyester products have flammability ratings from the CSA. See Table 1.3 for a list of grades having CSA ratings.

1.3.7 NSF

The NSF classification listings include Celanex PBT grades in both natural and black colors. See Table 1.3 for a list of grades. The NSF website can be checked for updates.

1.3.8 USDOT

Testing of 0.04-inch specimens according to specification MVSS 302 classifies flame-retarded Celanex PBT rades as self-extinguishing. Burn rates for various other polyester grades are given in Table 2.1.

Table 1.3 • Polyester Code Compliance

Agency	Code	Grade(s)
CSA	PBTP Flammability and Thermal Index	Celanex PBT 2016, 3116, 3200-2, 3216, 3226, 3300-2, 3316, 4300
		Vandar® PBT Alloy 8000
FDA	21 CFR 177.1660	Contact Technical Information (800) 833-4882 or email prodinfo@celanese.com for certification letters.
NSF/ANSI	Potable Water Standard 61	Celanex PBT 1462Z Natural, 2000-2 Black, 2000-3 Natural, 2002-2 Natural, 2002-3 Natural, 2003-2 Natural & Black, 3200-2 Natural & Black, 3300-2 Natural & Black
UL	Bobbin Insulation Class 130 (Class B)	Celanex PBT 1602Z, 2004-2, 3200-2
	Bobbin Insulation Class 155 (Class F)	Celanex PBT 1462Z, 2016, 3116, 3216, 3226, 3300-2, 3314, 3316, 5200, 5300, 6400
USP	Class VI / ISO 10933 Biocompatibility	Natural Celanex "MT" Grades

Table 1.4 • Military and Government Specifications for Celanex PBT

Code	Specification	Grade(s)	Classification
MIL-P-46161 (MR)	Plastics Molding Material, Polyterephthalate	3200, 3200-2	Grade B, Class 2
	Thermoplastics, Glass Fiber Reinforced	3300, 3300-2	Grade A, Class 3
MIL-E-5272C (ASG)	Fungus Resistance Test	3300, 3300-2	Pass
MIL-STD-810b-508 Conforming to CCC-T-191b-5762	Fungus Resistance Test Meeting Soil Burial Government Specification CCC-T-191b-5762	3300	Pass
MIL-M-24519 (Navy)	Molding Plastics, Electrical Thermoplastics	3314, 3316	GPT-30F

1.3.9 MIL-Spec and Other

Table 1.4 lists military and government specification compliance information for Celanex® PBT grades. Table 1.3 lists specific grades recognized or approved under the UL, FDA, USP, CSA and NSF codes.

1.3.10 ASTM

ASTM specifications for automotive applications are given in Table 1.5.

Table 1.5 • ASTM Specifications

Product	Description	Specification ID
Celanex® PBT		
1462Z	Natural, Black, High Carbon Black	ASTM D5927 TPES 011G30
1600A	Natural	ASTM D5927 TPES 0112
1602Z	Natural, Black	ASTM D5927 TPES 0113
1632Z	Natural, Black	ASTM D5927 TPES 011
1700A	Natural	ASTM D5927 TPES 0111
2000-2	Natural, Black	ASTM D5927 TPES 0116
2001	Natural	ASTM D5927 TPES 0112
2002-2	Color per drawing	ASTM D5927 TPES 0114
2002-2	Natural, Black	ASTM D5927 TPES 0114
2002-3	Natural	ASTM D5927 TPES 0114
2003-2	Natural, Black	ASTM D5927 TPES 0115
2003-3	Natural	ASTM D5927 TPES 0115
2016	Natural, Black	ASTM D5927 TPES B45100
3200	Natural	ASTM D5927 TPES 011G15
3200-2	Natural, Black	ASTM D5927 TPES 011G15
3216	Natural, Black	ASTM D5927 TPES 061R30
3216	Colors	ASTM D5927 TPES 0610 A3515
3300	Colors	ASTM D5927 TPES 011G30
3300	Natural	ASTM D5927 TPES 011G30
3300-2	Natural, Black	ASTM D5927 TPES 011G30
3300D	Black	ASTM D5927 TPES 011G30

Table 1.5 • ASTM Specifications

Product	Description	Specification ID
Celanex® PBT		
3300HR	Natural, Black	ASTM D5927 TPES 011G30 A45350
3300LM	Black	ASTM D5927 TPES
0110G30A46550		
3309HR	Black	ASTM D5927 TPES 011G30
3309HRT	Black	ASTM D5927 TPES 0110 A4545
3314	Black	ASTM D5927 TPES 013G30
3316	Natural, Black, Blue	ASTM D5927 TPES 013G30
3400-2	Natural, Black	ASTM D5927 011G40
4016	Natural, Black	ASTM D5927 TPES 0131
4300	Natural, Black	ASTM D5927 TPES 011G30
4302	Black	ASTM D5927 TPES 010 A4550
4305	Natural	ASTM D5927 TPES 0120G33 A4550
5200-2	Black	ASTM D5927 TPES 011G15
5300-2	Black	ASTM D4000 TPES 0610 G31
6407	Black	ASTM D5927 TPES 062R30
6500	Natural, Black	ASTM D5927 TPES 061R30
J600	Natural, Black	ASTM D5927 TPES 061R40
Impet® PBT		
2700A GV 1/45	Natural, Black	ASTM D5927 TPES 021G45
330R	Natural, Black	ASTM D5927 TPES 021G30
340R	Natural, Black	ASTM D5927 TPES 021G45

1.4 Product Support

Celanese provides its customers with comprehensive product support beginning with application assessment and going all the way to on-site molding assistance and part testing as shown in Figure 1.2. 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 using proprietary software. 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.

1.5 General Safety and Health

Standard precautions when working with hot molten plastics must be observed when processing any of Celanese's polyester resins. Before handling or processing any of the polyester materials, 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 MSDS to control workplace exposure to dust and volatiles.

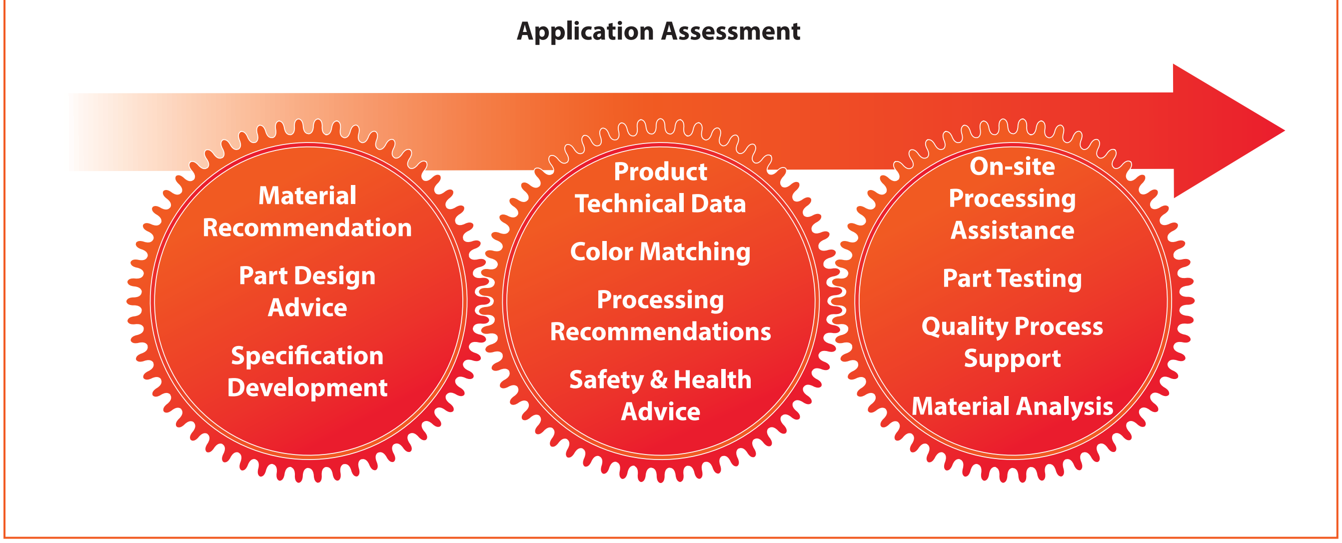
MSDS documentation can be obtained by contacting your Celanese representative, from Celanese Product Information Services at 1-800-833-4882 or on the Celanese web site: www.celanese .com.

1.6 Reference Publications

More information on plastics and on Celanese's polyester products is available on Celanese's web site and in the following Celanese publications:

- Designing with Plastics: The Fundamentals (TDM-1)
- Designing and Producing Plastic Gears
- Riteflex® TPE Technical Manual (TPE-001)

Figure 1.2 • Celanese Application Support Services



2. Properties

Celanese's extensive polyester product portfolio provides a very broad range of physical, mechanical and other properties. The various grades are in general characterized by excellent electrical properties and good chemical resistance. The following tables present typical short-term properties, grouped by product family and type, for representative products in the three product families. Data are presented for tests according to ISO (International Organization for Standardization) standards. Test data in accordance with ASTM (American Society for Testing and Materials) standards may be found on the Celanese web site, www.celanese .com.

Results of these standard tests conducted on laboratory specimens are guide values and are most useful for comparing different materials under the standardized test conditions. They are not necessarily representative of the properties of finished end-user parts, which are affected by part design and processing conditions. This is particularly the case for glass-reinforced materials where flow orientation of the reinforcing fibers can cause significant anisotropy in molded parts.

2.1 Properties of Polyester Resins

Table 2.1 lists physical, mechanical, thermal and electrical properties of Celanese's polyester resins, Celanex® PBT, Impet® PET and Vandar® PBT alloys.

Table 2.1 • Physical, Mechanical,

	Method	Units
Physical Properties		
Density	ISO 1183	kg/m^3
Melt flow rate (MFR)	ISO 1133	g/10 min
MFR test temperature	ISO 1133	°C
MFR test load	ISO 1133	Kg
Mold shrinkage – parallel	ISO 294-4	%
Mold shrinkage – normal	ISO 294-4	%
Humidity absorption (23°C/50%RH)		
– 24 hr	ISO 62	%
– Saturation	ISO 62	%
Shore hardness D scale 15 sec value	ISO 868	
Mechanical Properties		
Tensile modulus (1mm/min)	ISO 527-2/1A	MPa
Tensile stress at yield (50mm/min)	ISO 527-2/1A	MPa
Tensile strain at yield (50mm/min)	ISO 527-2/1A	%
Nominal strain at break (50mm/min)	ISO 527-2/1A	%
Tensile stress at 50% strain (50mm/min)	ISO 527-2/1A	MPa
Tensile stress at break (50mm/min)	ISO 527-2/1A	MPa
Tensile strain at break (50mm/min)	ISO 527-2/1A	%
Tensile stress at break (5mm/min)	ISO 527-2/1A	MPa
Tensile strain at break (5mm/min)	ISO 527-2/1A	%
Flexural modulus (23°C)	ISO 178	MPa
Flexural strength (23°C)	ISO 178	MPa
Charpy impact strength @ 23°C	ISO 179/1eU	KJ/m^2
Charpy impact strength @ -30°C	ISO 179/1eU	KJ/m^2
Charpy notched impact strength @ 23°C	ISO 179/1eA	KJ/m^2
Charpy notched impact strength @ -30°C	ISO 179/1eA	KJ/m^2
Notched impact strength (Izod) @ 23°C	ISO 180/1A	KJ/m^2
Thermal Properties		
Melting temperature (10°C/min)	ISO 11357-1,-2,-3	°C
Glass transition temperature (10°C/min)	ISO 11357-1,-2,-3	°C
DTUL @ 1.8 MPa	ISO 75-1, -2	°C
DTUL @ 0.45 MPa	ISO 75-1, -2	°C
Coeff. of linear therm expansion – parallel	ISO 11359-2	E-4/°C
Coeff. of linear therm expansion – normal	ISO 11359-2	E-4/°C
Flammability at thickness h	UL94	Class
thickness tested (h)	UL94	mm
Electrical Properties		
Relative permittivity		
– 100Hz (dielectric constant)	IEC 60250	
– 1MHz (dielectric constant)	IEC 60250	
Dissipation factor – 100Hz	IEC 60250	E-4
Dissipation factor – 1MHz	IEC 60250	E-4
Volume resistivity	IEC 60093	ohm-m
Surface resistivity	IEC 60093	ohm
Dielectric Strength*	IEC 60243-1	KV/mm
Comparative tracking index CTI	IEC 60112	—

*Not equivalent to ASTM D149
n/a = not available

Thermal and Electrical Properties of Polyester Resins

Celanex®PBT									
UNREINFORCED					GLASS REINFORCED			GLASS REINFORCED IMPROVED IMPACT	
1600A	1700A	2001	2002-2	2008	3200	3300	3400-2	4202	4300
1310	1310	1310	1310	1310	1410	1530	1610	1380	1530
6.5 250 2.16	4.5 250 2.16	7.4 250 2.16	18 250 2.16	175 250 2.16	26.0 250 2.16	17.0 250 2.16	8.0 250 2.16	4.5 250 2.16	8.0 250 2.16
1.8-2.0 1.8 -2.0	1.8-2.0 1.8 to 2.0	1.8-2.0 1.8 -2.0	1.8-2.0 1.8-2.0	1.8-2.0 1.8-2.0	0.1 0.9	0.3-0.5 0.7-0.9	0.3-0.5 0.7	0.4 0.9	0.3-0.5 0.8
0.06 0.19	0.06 0.19	0.06 0.19	0.06 0.19	0.04 0.17	0.04 0.17	0.04 0.16	0.04 0.12	0.06 0.16	0.05 0.14
77	80	79	78	81	82	84	85	79	83
2550	2500	2600	2600	2600	5800	9200	12100	5200	9300
60	60	60	60	n/a	n/a	n/a	n/a	n/a	n/a
5	6	6	4	n/a	n/a	n/a	n/a	n/a	n/a
>50	>50	>50	>50	n/a	n/a	n/a	n/a	n/a	n/a
28	28	33	30	n/a	n/a	n/a	n/a	n/a	n/a
33 115	35 120	37 200	35 220	47 2	n/a n/a	n/a n/a	n/a n/a	n/a n/a	n/a n/a
n/a n/a	n/a n/a	n/a n/a	n/a n/a	60 5	100 3.5	130 2.5	140 2.4	86 4.4	130 3.1
2200	2200	2500	2500	2200	5200	9700	11000	5100	9000
80	80	80	80	80	150	210	215	141	205
NB 210	NB 220	NB NB	NB 190	38 44	20 20	46 45	47 45	52 37	40 51
7 6.5	7.5 7.0	7.0 4.2	6 6	2.8 2.1	5.5 5	8.5 8.5	11 9.5	11 5.7	11 8.5
5.5	5.5	5.5	5.0	3.1	5	7.5	10	12	12
225	225	225	225	225	225	225	225	225	225
60	60	60	60	60	60	60	n/a	44	41
50 150	50 150	50 150	55 150	57 155	195 215	205 225	212 225	183 216	200 220
1.1 1.0	1.1 0.92	1.3 0.88	1.1 1.4	1.1 1	0.40 1.1	0.25 1.0	0.15 1.01	0.36 1.0	0.24 0.8
HB 0.75	HB 0.75	n/a n/a	HB 0.71	n/a n/a	HB 0.71	HB 0.71	HB 0.71	n/a n/a	HB 0.71
4.0 3.5	4.0 3.6	3 3.2	4 3.5	3.3 3.2	4.2 3.8	4.5 4.1	3.5 3.4	3.4 3.2	2.8 3.9
14 210	14 210	<10 200	14 220	<10 200	16 200	22 160	<10 130	<10 200	<10 220
>1E13	>1E13	>1E13	>1E14	>1E13	>1E14	>1E15	>1E15	>1E14	>1E15
>1E15	>1E15	>1E15	1E15	>1E15	>1E15	>1E15	1E15	1.10E+17	1E15
22	22	15	30	15	30	44	44	22	44
600	600	600	600	350	350	425	n/a	>600	400

2

Table 2.1 • Physical, Mechanical,

	Method	Units	FLAME RETARDANT					
			2016	**4016**	**3216**	**3316**	**7716**	**XFR 6842** GF30
Physical Properties								
Density	ISO 1183	kg/m^3	1440	1450	1540	1660	1690	1530
Melt flow rate (MFR)	ISO 1133	g/10 min	25.0	8.7	18	12	6.3	34
MFR test temperature	ISO 1133	°C	250	250	250	250	250	250
MFR test load	ISO 1133	Kg	2.16	2.16	2.16	2.16	2.16	2.16
Mold shrinkage – parallel	ISO 294-4	%	~2.8	-1.7	~0.5	~0.4	~0.3	~0.4
Mold shrinkage – normal	ISO 294-4	%	~1.6	-1.9	~1.1	~0.8	~0.7	~1.1
Humidity absorption (23°C/50%RH)								
– 24 hr	ISO 62	%	0.05	0.07	0.04	0.04	0.03	n/a
– Saturation	ISO 62	%	0.17	0.16	0.17	0.16	0.1	n/a
Shore hardness D scale 15 sec value	ISO 868		81	80	82	85	83	n/a
Mechanical Properties								
Tensile modulus (1mm/min)	ISO 527-2/1A	MPa	3000	2800	6700	10700	10800	10800
Tensile stress at yield (50mm/min)	ISO 527-2/1A	MPa	60	55	n/a	55	n/a	n/a
Tensile strain at yield (50mm/min)	ISO 527-2/1A	%	3	3.7	n/a	3.7	n/a	n/a
Nominal strain at break (50mm/min)	ISO 527-2/1A	%	10	38	n/a	38	n/a	n/a
Tensile stress at break (5mm/min)	ISO 527-2/1A	MPa	n/a	n/a	100	135	83	100
Tensile strain at break (5mm/min)	ISO 527-2/1A	%	n/a	n/a	2.5	2.5	1.6	2.1
Flexural modulus (23°C)	ISO 178	MPa	3100	2630	6000	10300	11650	n/a
Flexural strength (23°C)	ISO 178	MPa	95	76	155	200	140	n/a
Charpy impact strength @ 23°C	ISO 179/1eU	KJ/m^2	55	245	28	42	22	35
Charpy impact strength @-30°C	ISO 179/1eU	KJ/m^2	55	105	28	42	n/a	n/a
Charpy notched impact strength @ 23°C	ISO 179/1eA	KJ/m^2	4.0	8.1	6	8.5	5	6.8
Charpy notched impact strength @-30°C	ISO 179/1eA	KJ/m^2	4.5	8.1	6	8.5	5	n/a
Notched impact strength (Izod) @ 23°C	ISO 180/1A	KJ/m^2	4.5	7.7	5.5	7.7	4.9	n/a
Thermal Properties								
Melting temperature (10°C/min)	ISO 11357-1,-2,-3	°C	225	225	225	225	225	225
Glass transition temperature (10°C/min)	ISO 11357-1,-2,-3	°C	60	48	60	48	60	n/a
DTUL @ 1.8 MPa	ISO 75-1, -2	°C	68	62	200	208	194	203
DTUL @ 0.45 MPa	ISO 75-1, -2	°C	165	159	217	220	222	n/a
Coeff. of linear therm expansion – parallel	ISO 11359-2	E-4/°C	0.63	1.0	0.36	0.25	0.31	n/a
Coeff. of linear therm expansion – normal	ISO 11359-2	E-4/°C	0.77	1.0	1.0	0.77	0.46	n/a
Flammability at thickness h	UL94	Class	V-0	V-0	V-0	V-0	V-0	V-0
thickness tested (h)	UL94	mm	0.75	0.85	0.38	0.38	0.90	0.8
Electrical Properties								
Relative permittivity								
– 100Hz (dielectric constant)	IEC 60250		3.6	3.1	3.7	3.6	4.2	n/a
– 1MHz (dielectric constant)	IEC 60250		3.5	3.1	3.5	2.9	3.9	n/a
Dissipation factor – 100Hz	IEC 60250	E-4	47	<10	33	33	<10	n/a
Dissipation factor – 1MHz	IEC 60250	E-4	185	200	160	145	190	n/a
Volume resistivity	IEC 60093	ohm-m	>1E16	>1E14	>1E16	>1E16	>1E14	>1E17
Surface resistivity	IEC 60093	ohm	>1E15	>1E15	>1E15	>1E15	>1E16	n/a
Dielectric strength*	IEC 60243-1	KV/mm	39	27	23	23	26	27
Comparative tracking index CTI	IEC 60112	—	250	250	250	250	200	500

*Not equivalent to ASTM D149
n/a = not available

Thermal and Electrical Properties of Polyester Resins

Celanex® PBT

NON-HALOGENATED FLAME RETARDANT				GLASS REINFORCED – SURFACE FINISH						GLASS/MINERAL		
XFR 6842 GF20	XFR 6842 GF15	XFR 6842 GF10	XFR 4840	5202	5202HF	5205HG	5214HF	5300	5314	J600	6500	6500HF
1450	1420	1400	1340	1440	1450	1450	1580	1540	1720	1620	1550	1550
10	18	10	11	25	48	n/a	36	23	n/a	11.0	22.0	42
250	250	250	250	265	265	n/a	265	265	250	265	265	265
2.16	2.16	2.16	2.16	2.16	2.16	n/a	2.16	2.16	2.16	2.16	2.16	2.16
~0.5	~0.6	~1.0	~2.2	0.1	0.4 - 0.6	0.4 - 0.6	0.1 - 0.6	0.3 - 0.5	0 - 0.5	0.4 - 0.9	0 - 0.5	0 - 0.5
~1.2	~1.1	~1.5	~1.8	0.7	0.1	n/a	0.6	0 - 0.5	0.1 - 0.6	0.6 - 1.2	0.5 - 0.8	0.5 - 0.8
n/a	n/a	n/a	n/a	0.06	0.04	n/a	0.04	0.06	0.03	0.06	0.06	0.06
n/a	n/a	n/a	n/a	0.17	0.15	n/a	0.15	0.17	0.1	0.19	0.19	0.19
n/a	n/a	n/a	n/a	83	84	n/a	83	85	86	84	85	85
8100	6900	5900	3300	6100	6300	6400	7200	10000	11400	11000	9700	9700
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
88	79	70	45	100	82	95	77	135	125	104	125	125
2.7	3.1	3.3	13.3	2.5	1.5	1.8	1.3	3	1.6	1.9	2.2	2.2
n/a	n/a	n/a	n/a	5300	5900	6300	6440	9000	10500	11000	9500	9500
n/a	n/a	n/a	n/a	150	140	135	109	200	182	155	180	180.0
35	32	30	32	15	16	n/a	17	49	29	38	30	27
n/a	n/a	n/a	n/a	17	16	n/a	15	48	23	40	30	24
6.2	5.5	4.2	3	4.7	4.5	4.7	4.5	9.5	7.0	6.5	7.1	6.7
n/a	n/a	n/a	n/a	4.5	4.8	n/a	4.5	9	7.3	6.5	6.4	7.2
n/a	n/a	n/a	n/a	4.4	4.5	4.5	4.4	8.3	7.6	5.1	5.3	5.3
225	225	225	225	225	225	265	225	225	225	225	225	225
n/a	n/a	n/a	n/a	50	n/a	n/a	n/a	60	n/a	54	54	54
196	194	173	70	180	182	180	155	200	202	190	202	202
n/a	n/a	n/a	n/a	215	219	220	206	220	222	220	223	223
n/a	n/a	n/a	n/a	0.42	n/a	n/a	n/a	0.2	n/a	0.20	0.28	0.28
n/a	n/a	n/a	n/a	0.73	n/a	n/a	n/a	n/a	n/a	0.68	0.85	0.85
V-0	V-0	V-0	V-0	HB	n/a	HB	V-0	HB	V-0	HB	n/a	n/a
0.8	0.8	0.8	0.8	0.8	n/a	0.8	0.8	0.71	0.8	0.82	n/a	n/a
n/a	n/a	n/a	n/a	2.7	3.5	n/a	3.3	3.6	4	5.1	3.5	3.3
n/a	n/a	n/a	n/a	2.7	3.6	n/a	3.6	12	3.9	4.4	3.8	3.1
n/a	n/a	n/a	n/a	<10	<10	n/a	<10	<10	<10	100	<10	<10
n/a	n/a	n/a	n/a	140	190	n/a	200	120	170	220	400	120
>1E14	>1E14	>1E15	>1E16	>1E15	>1E15	n/a	>1E14	>1E13	>1E14	>1E13	>1E14	>1E14
n/a	n/a	n/a	n/a	>1E15	>1E17	n/a	>1E15	>1E15	>1E17	>1E15	>1E16	>1E16
24	21	23	17	17	30	n/a	15	30	17	35	22	31
425	450	450	600	225	225	n/a	275	350	n/a	350	325	325

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Table 2.1 • Physical, Mechanical,

	Method	Units	HYDROLYSIS RESISTANCE					
			2003HR	3209HR	3309HR	3309HRHF	3309HRT	3316HR
Physical Properties								
Density	ISO 1183	kg/m^3	1310	1410	1540	1530	1500	1607
Melt flow rate (MFR)	ISO 1133	g/10 min	44	30.0	17.0	9.7	22	6
MFR test temperature	ISO 1133	°C	250	250	250	250	250	250
MFR test load	ISO 1133	Kg	2.16	2.16	2.16	2.16	2.16	2.16
Mold shrinkage – parallel	ISO 294-4	%	1.8-2.0	0.1	0.3-0.5	0 - .5	0 - 0.5	n/a
Mold shrinkage – normal	ISO 294-4	%	1.8-2.0	0.9	0.7-0.9	0.5 - 0.8	0.7	n/a
Humidity absorption (23°C/50%RH)								
– 24 hr	ISO 62	%	0.04	0.04	0.04	0.04	0.04	0.04
– Saturation	ISO 62	%	0.14	0.17	0.16	0.16	0.16	0.16
Shore hardness D scale 15 sec value	ISO 868		78	82	85	85	82	n/a
Mechanical Properties								
Tensile modulus (1mm/min)	ISO 527-2/1A	MPa	2700	5800	9200	10400	8700	9850
Tensile stress at yield (50mm/min)	ISO 527-2/1A	MPa	60	n/a	n/a	n/a	n/a	n/a
Tensile strain at yield (50mm/min)	ISO 527-2/1A	%	4	n/a	n/a	n/a	n/a	n/a
Nominal strain at break (50mm/min)	ISO 527-2/1A	%	40	n/a	n/a	n/a	n/a	n/a
Tensile stress at 50% strain (50mm/min)	ISO 527-2/1A	MPa	n/a	n/a	n/a	n/a	n/a	n/a
Tensile stress at break (50mm/min)	ISO 527-2/1A	MPa	55	n/a	n/a	n/a	n/a	n/a
Tensile strain at break (50mm/min)	ISO 527-2/1A	%	25	n/a	n/a	n/a	n/a	n/a
Tensile stress at break (5mm/min)	ISO 527-2/1A	MPa	n/a	100	139	150	115	115
Tensile strain at break (5mm/min)	ISO 527-2/1A	%	n/a	3.5	2.7	2.6	2.8	2.5
Flexural modulus (23°C)	ISO 178	MPa	2550	5300	9700	9700	9000	8950
Flexural strength (23°C)	ISO 178	MPa	80	150.0	210	220.0	190	175
Charpy impact strength @ 23°C	ISO 179/1eU	KJ/m^2	111	22	46	44	53	n/a
Charpy impact strength @-30C	ISO 179/1eU	KJ/m^2	35	22	45	39	38	n/a
Charpy notched impact strength @ 23°C	ISO 179/1eA	KJ/m^2	4.3	5.5	8.5	8.0	10	8.5
Charpy notched impact strength @-30°C	ISO 179/1eA	KJ/m^2	4.3	4	8.5	9.1	10	n/a
Notched impact strength (Izod) @ 23°C	ISO 180/1A	KJ/m^2	4.0	5.3	12	9.0	10	n/a
Thermal Properties								
Melting temperature (10°C/min)	ISO 11357-1,-2,-3	°C	225	225	225	225	225	225
Glass transition temperature (10°C/min)	ISO 11357-1,-2,-3	°C	n/a	60	60	60	n/a	n/a
DTUL @ 1.8 MPa	ISO 75-1, -2	°C	55	180	205	210	208	202
DTUL @ 0.45 MPa	ISO 75-1, -2	°C	150	220	225	222	222	n/a
Coeff. of linear therm expansion (parallel)	ISO 11359-2	E-4/°C	1.2	0.36	0.25	0.19	n/a	n/a
Coeff. of linear therm expansion (normal)	ISO 11359-2	E-4/°C	1.1	1	1.0	1.0	n/a	n/a
Flammability at thickness h	UL94	Class	HB	HB	HB	HB	HB	V-0/0.75
Electrical Properties								
Relative permittivity								
– 100Hz (dielectric constant)	IEC 60250		3.1	3.7	4.5	2.8	2.8	n/a
– 1MHz (dielectric constant)	IEC 60250		3.2	2.9	4.1	3.2	2.8	2.9
Dissipation factor – 100Hz	IEC 60250	E-4	<10	<10	22	<10	<10	n/a
Dissipation factor – 1MHz	IEC 60250	E-4	200	240	160	140	110	145
Volume resistivity	IEC 60093	ohm-m	>1E13	4.05E+14	>1E13	1.80E+15	1.20E+15	>1E13
Surface resistivity	IEC 60093	ohm	>1E15	1.5E+16	>1E15	1.60E+15	1.90E+17	>1E15
Dielectric strength*	IEC 60243-1	KV/mm	15	17	31	22	38	n/A
Comparative tracking index CTI	IEC 60112	—	600	325	425	425	450	250

*Not equivalent to ASTM D149
n/a = not available

Thermal and Electrical Properties of Polyester Resins

Celanex® PBT

		HEAT SHOCK			OTHER SPECIAL	
4309AR	3425HRT	4302HS	531HS	JKX1151	6035GB20	LW233R
1440	1580	1490	1470	1480	1460	1640
13	25	8.0	16	5	15.0	10
265	250	250	250	250	250	265
5.0	2.16	2.16	2.16	5	2.16	2.16
n/a	0 - 0.5	0.2-0.4	0 - 0.5	0.2	1.5	0.1
n/a	0.6 - 0.9	.4-.6	0.7	0.5	1.5	0.4
0.04	0.04	0.06	0.06	0.06	0.06	0.06
0.16	0.12	0.15	0.19	0.19	0.19	0.19
n/a	81	81	80	78	80	77
8100	9100	8500	8300	n/a	3300	4100
n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a
100	107	120	105	57	46	40
3	3	2.8	3.5	3.6	8.5	3
7600	8500	8700	7400	5880	3300	4609
150	165	190	175.0	95	80.0	68
45	53	56	47	34	22	22
n/a	44	41	38	33	19	54
10	11	9.9	11.0	6.9	1.7	7.0
n/a	9.4	8.3	8	5.4	2.8	3.1
9	11	14	13.0	7.9	3.5	7.3
225	225	225	225	225	225	225
n/a	n/a	n/a	n/a	n/a	n/a	n/a
191	175	173	204	170	72	95
217	202	218	221	211	168	193
0.23	n/a	0.23	n/a	n/a	n/a	n/a
0.95	n/a	0.24	n/a	n/a	n/a	n/a
HB	HB	HB	HB	HB	HB	HB
n/a	4.2	3.2	2.8	3.4	3.7	n/a
n/a	4.1	2.5	3	3.4	3.5	n/a
n/a	<10	<10	<10	n/a	<10	n/a
n/a	200	100	130	n/a	170	n/a
n/a	1.2E+14	1.90E+14	1.90E+13	4.20E+13	3.20E+14	7.20E+12
n/a	3.2E+17	1.30E+17	8.90E+15	2.20E+16	9.50E+16	9.70E+15
n/a	31	19	32	32	30	28
n/a	375	300	n/a	n/a	275	n/a

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Table 2.1 • Physical, Mechanical, Thermal and Electrical Properties of Polyester Resins

			Impet® PET		
			GLASS REINFORCED		
	Method	**Units**	**330R**	**340R**	**830R**
Physical Properties					
Density	ISO 1183	kg/m^3	1580	1700	1600
Melt flow rate (MFR)	ISO 1133	g/10 min	6.1	2.7	
MFR test temperature	ISO 1133	°C	280	280	
MFR test load	ISO 1133	Kg	2.16	2.16	
Mold shrinkage – parallel	ISO 294-4	%	0.1-0.3	0.1-0.2	0.1-0.3
Mechanical Properties					
Tensile modulus (1mm/min)	ISO 527-2/1A	MPa	11000	16800	10700
Tensile stress at break (5mm/min)	ISO 527-2/1A	MPa	170	190	118
Tensile strain at break (5mm/min)	ISO 527-2/1A	%	2.6	2.1	2.1
Flexural modulus (23°C)	ISO 178	MPa	11000	15000	11000
Flexural strength (23°C)	ISO 178	MPa	270	290	190
Charpy impact strength @ 23°C	ISO 179/1eU	KJ/m^2	48		
Charpy impact strength @-30°C	ISO 179/1eU	KJ/m^2	45		
Charpy notched impact strength @ 23°C	ISO 179/1eA	KJ/m^2	10	14.5	7
Charpy notched impact strength @-30°C	ISO 179/1eA	KJ/m^2	10		
Thermal Properties					
Melting temperature (10°C/min)	ISO 11357-1,-2,-3	°C	250	250	
DTUL @ 1.8 MPa	ISO 75-1, -2	°C	224	229	216
DTUL @ 0.45 MPa	ISO 75-1, -2	°C	240	252	235
Coeff. of linear therm expansion – parallel	ISO 11359-2	E-4/°C	0.32	0.68	0.31
Coeff. of linear therm expansion – normal	ISO 11359-2	E-4/°C	0.77	0.65	0.72
Melting point (peak)	ISO 3146	°C			252

Table 2.1 • Physical, Mechanical, Thermal and Electrical Properties of Polyester Resins

			Vandar® PBT Alloys					
			UNREINFORCED				GLASS REINFORCED	
	Method	Units	2100	2500	4602Z	8000	4632Z	4662Z
Physical Properties								
Density	ISO 1183	kg/m^3	1230	1250	1250	1310	1340	1470
Melt flow rate (MFR)	ISO 1133	g/10 min	n/a	13	n/a	n/a	n/a	n/a
MFR test temperature	ISO 1133	°C	n/a	250	n/a	n/a	n/a	n/a
MFR test load	ISO 1133	Kg	n/a	5	n/a	n/a	n/a	n/a
Mold shrinkage – parallel	ISO 294-4	%	1.7-2.2	1.7-2.2	1.7-2.2	2.5-2.8	0.4-0.6	0.3-0.5
Mold shrinkage – normal	ISO 294-4	%	1.7-2.2	1.7-2.2	1.7-2.2		1.2-1.4	1.2-1.4
Humidity Absorption (23°C/50% RH)	ISO 62	%	0.2	n/a	0.2	0.2	0.2	0.2
Shore hardness D scale 15 sec value	ISO 868		n/a	75	n/a	n/a	n/a	n/a
Mechanical Properties								
Tensile modulus (1mm/min)	ISO 527-2/1A	MPa	1600	1450	1500	1700	4000	7000
Tensile stress at yield (50mm/min)	ISO 527-2/1A	MPa	40	35	40	30	n/a	n/a
Tensile strain at yield (50mm/min)	ISO 527-2/1A	%	4	5	6	4.5	n/a	n/a
Nominal strain at break (50mm/min)	ISO 527-2/1A	%	>50	>50	>50	>50	n/a	n/a
Tensile stress at 50% strain (50mm/min)	ISO 527-2/1A	MPa	26	n/a	26	32	n/a	n/a
Tensile stress at break (50mm/min)	ISO 527-2/1A	MPa	28	35	n/a	n/a	n/a	n/a
Tensile strain at break (50mm/min)	ISO 527-2/1A	%	n/a	n/a	n/a	50	n/a	n/a
Flexural modulus (23°C)	ISO 178	MPa	1800	1500	1400	1650	3800	6700
Flexural strength (23°C)	ISO 178	MPa	60	50	45	50	100	130
Charpy impact strength @ 23°C	ISO 179/1eU	KJ/m^2	n/a	203	n/a	n/a	65	70
Charpy impact strength @ -30°C	ISO 179/1eU	KJ/m^2	n/a	168	n/a	n/a	62	70
Charpy notched impact strength @ 23°C	ISO 179/1eA	KJ/m^2	70	88	70	75	18	20
Charpy notched impact strength @ -30°C	ISO 179/1eA	KJ/m^2	16	9	10	15	8	10
Notched impact strength (Izod) @ 23°C	ISO 180/1A	KJ/m^2	n/a	n/a	n/a	n/a	17	21
Thermal Properties								
Melting temperature (10°C/min)	ISO 11357-1,-2,-3	°C	225	225	225	225	225	225
Glass transition temperature (10°C/min)	ISO 11357-1,-2,-3	°C	60	n/a	60	n/a	60	60
DTUL @ 1.8 MPa	ISO 75-1, -2	°C	50	50	48	52	154	175
DTUL @ 0.45 MPa	ISO 75-1, -2	°C	110	125	110	127	210	218
Coeff. of linear therm expansion – parallel	ISO 11359-2	E-4/°C	1.3	1.3	1.3	1.1	0.25	0.15
Coeff. of linear therm expansion – normal	ISO 11359-2	E-4/°C	n/a	1.34	n/a	n/a	1.41	1.27
Flammability at thickness h	UL94	Class	HB	n/a	HB	V-0	HB	HB
thickness tested (h)	UL94	mm	1.6	n/a	0.85	0.85	1.5	1.5
Melting point (peak)	ISO 3146	°C	225	n/a	n/a	n/a	n/a	n/a
Electrical Properties								
Relative permittivity								
– 100Hz / dielectric constant	IEC 60250		4	3.08	4.4	4	4.6	4.9
– 1MHz/ dielectric constant	IEC 60250		3.6		3.9	3.6	4.1	4.3
Dissipation factor – 100Hz	IEC 60250	E-4	70	0.019	75	45	70	70
Dissipation factor – 1MHz	IEC 60250	E-4	200		310	170	290	260
Volume resistivity	IEC 60093	ohm-m	1.00E+12	1.70E+13	1.00E+12	1.00E+12	>1E12	>1E12
Surface resistivity	IEC 60093	ohm	1.00E+14	1.20E+16	1.00E+14	1.00E+14	>1E14	>1E14
Dielectric strength	IEC 60243-1	KV/mm	24	15	24	24	30	33
Comparative tracking index CTI	IEC 60112	—			600	600	425	425

2.2 Temperature Effects

The mechanical properties of materials typically decrease with increasing temperature. The strength and stiffness of semi-crystalline materials such as Celanese's PBT and PET polyester product lines fall off slowly with temperature until they reach their glass transition temperatures (Tg), above which their amorphous regions become rubbery and behave accordingly. Incorporation of reinforcements such as glass fibers significantly reduces this drop-off in mechanical properties so that glass-reinforced Celanex® PBT, Impet® PET and Vandar® PBT Alloy resins retain their outstanding mechanical properties at elevated temperatures.

Figure 2.1 shows a semi-log plot of normalized flexural modulus values measured by Dynamic Mechanical Analysis (DMA) for neat PBT polymer and 30% glass-reinforced grades. The point at which the final downward curvature of the plot occurs is often considered the highest useful temperature of the material, i.e., the temperature at which a part made from the material will still exhibit useful form retention under some degree of load.

Designers should exercise extreme care and evaluate prototype parts whenever operating requirements call for thermal exposure close to the DMA temperature of final downward property curvature.

Flexural strength and stiffness curves for various reinforced grades of Celanex PBT are shown in Figures 2.2 through 2.5. Figure 2.6 shows similar curves for the tensile strength of two unfilled high-impact grades of Vandar PBT alloy.

2.3 Stress-Strain Curves and Temperature

Just as strength and initial modulus values fall off with temperature, so also do stress values associated with given levels of strain. Ambient temperature stressstrain and secant modulus-strain curves are shown in Figures 2.7 through 2.9 for unreinforced grades of Celanex PBT and Vandar PBT Alloy, 7.5% to 30% glass-reinforced grades of Celanex PBT and glass/mineral reinforced grades of Impet PET.

The influence of temperature on unreinforced Celanex PBT 2002-2 may be seen in Figure 2.10, which presents data at temperatures between -40°C and 120°C for tensile stress-strain and secant modulus-strain properties. The divergence between values at 23°C and 80°C reflects passage through Tg. A similar divergence is found in reinforced grades, although of course the absolute values are higher. This is shown in Figures 2.11 through 2.15, illustrating the behavior of Celanex PBT with 15% and 30% glass reinforcement, Celanex PBT with different glass/mineral reinforcements and Impet PET with different glass/mineral reinforcements.

Fig. 2.1 • Typical Normalized DMA for Celanex® PBT

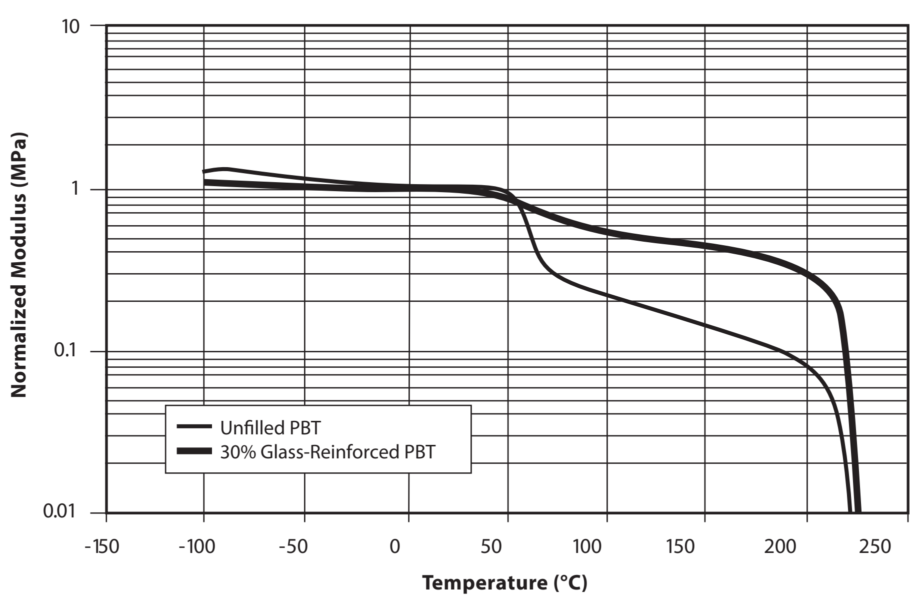

Fig. 2.2 • Flexural Modulus vs. Temperature for Glass Reinforced, General Purpose Grades of Celanex® Thermoplastic Polyester

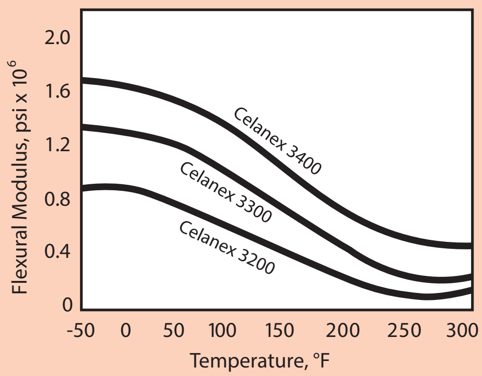

Fig. 2.3 • Flexural Modulus vs. Temperature for Glass Reinforced, Improved Impact/Surface Finish Grades of Celanex® Thermoplastic Polyester

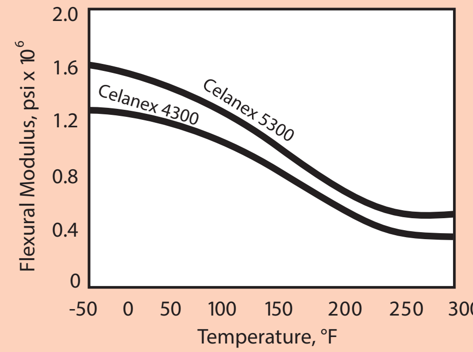

Fig. 2.4 • Flexural Strength vs. Temperature for Glass Reinforced, General Purpose Grades of Celanex® Thermoplastic Polyester

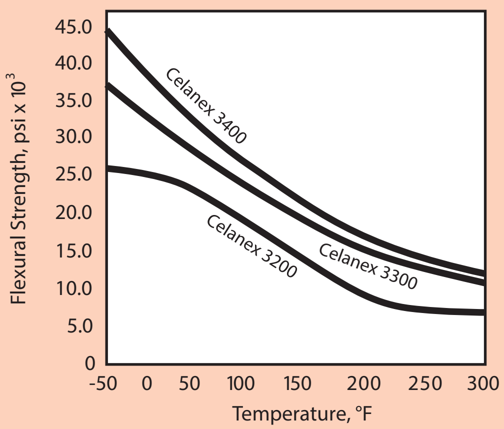

Fig. 2.5 • Flexural Strength vs. Temperature for Glass Reinforced, Improved Impact/Surface Finish Grades of Celanex® Thermoplastic Polyester

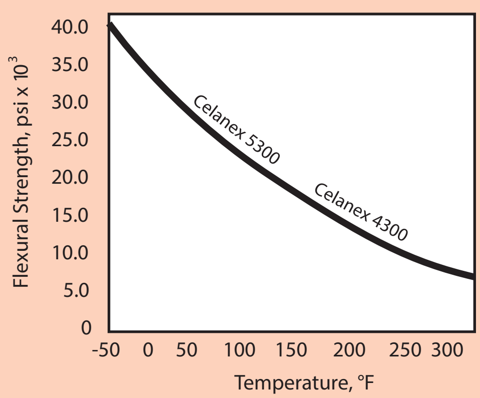

Fig. 2.6 • Tensile Strength vs. Temperature for Vandar® PBT Alloy

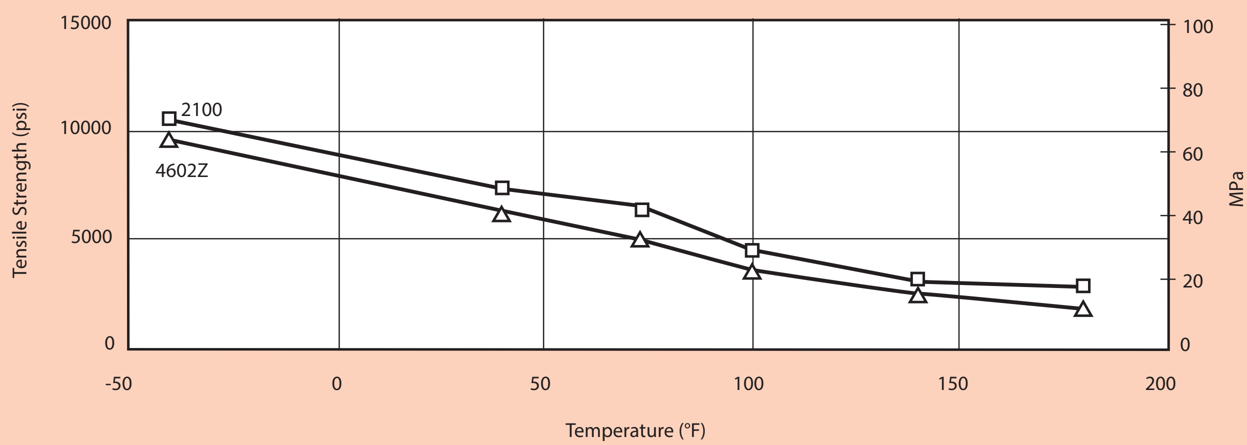

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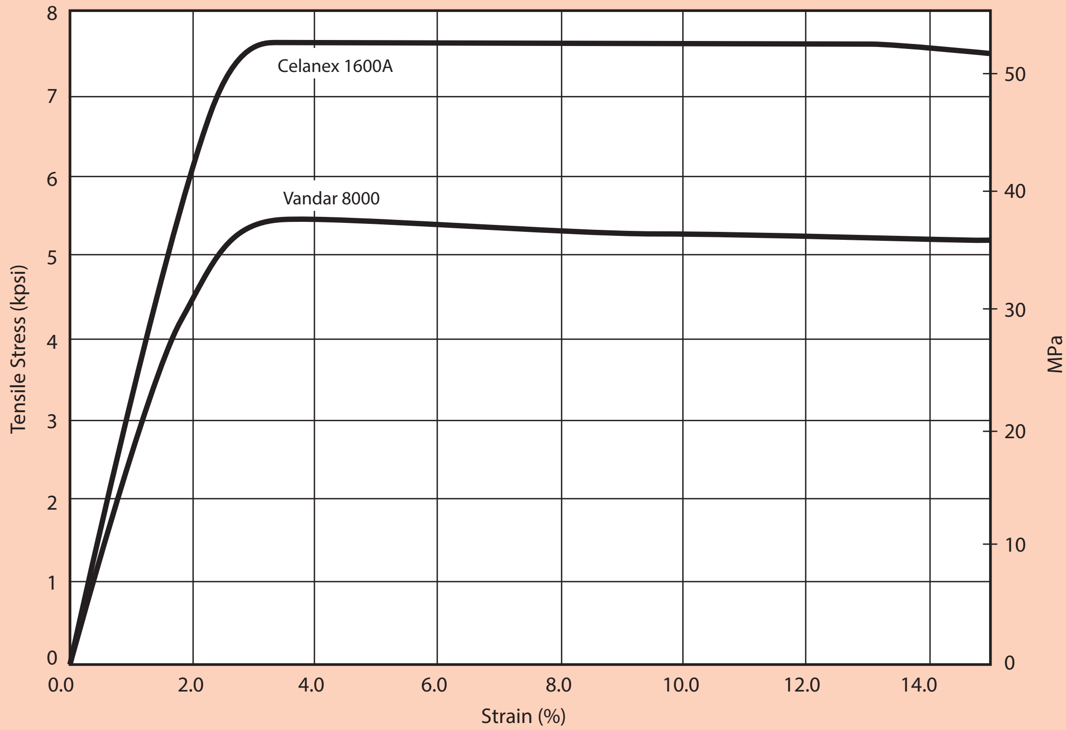
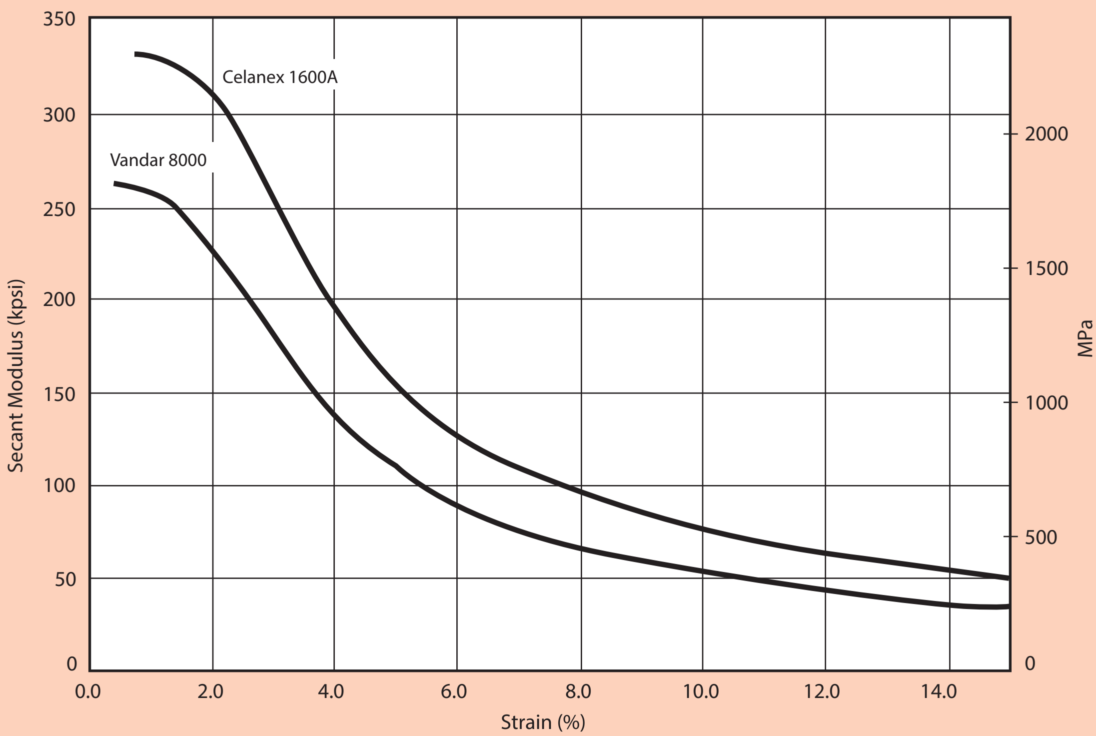
Fig. 2.7 • Typical Tensile Stress and Secant Modulus Plots for Some Unreinforced Grades of Celanex® Thermoplastic Polyester and Vandar® PBT Alloy

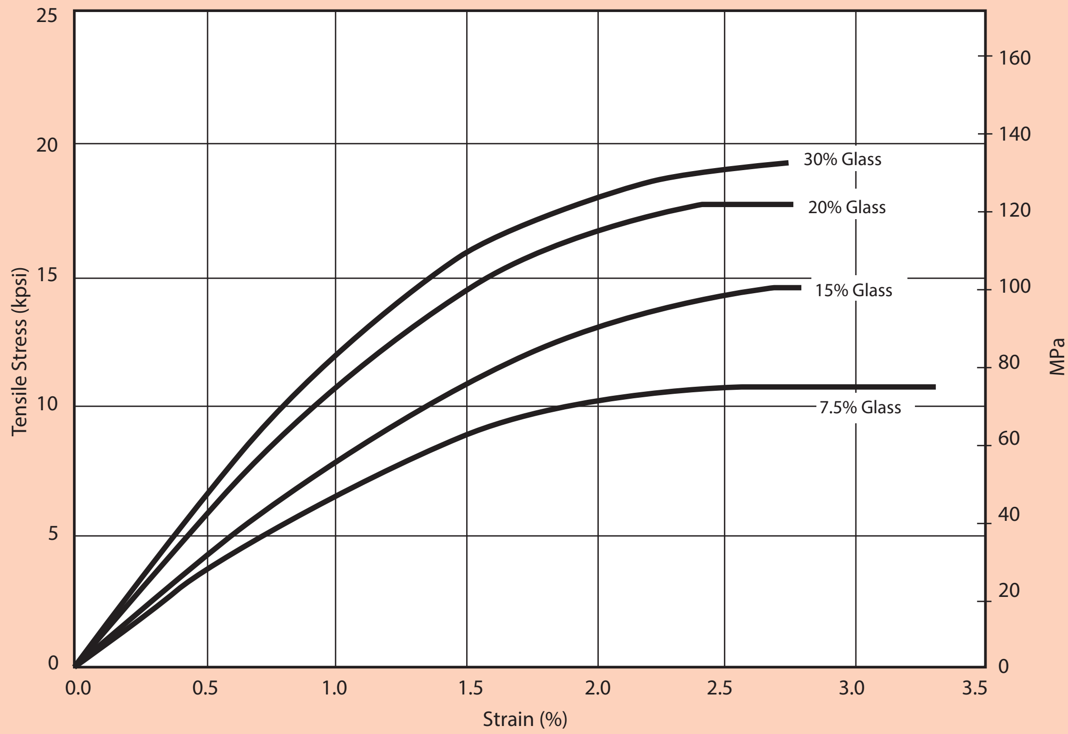


Tensile Stress-Strain Plots

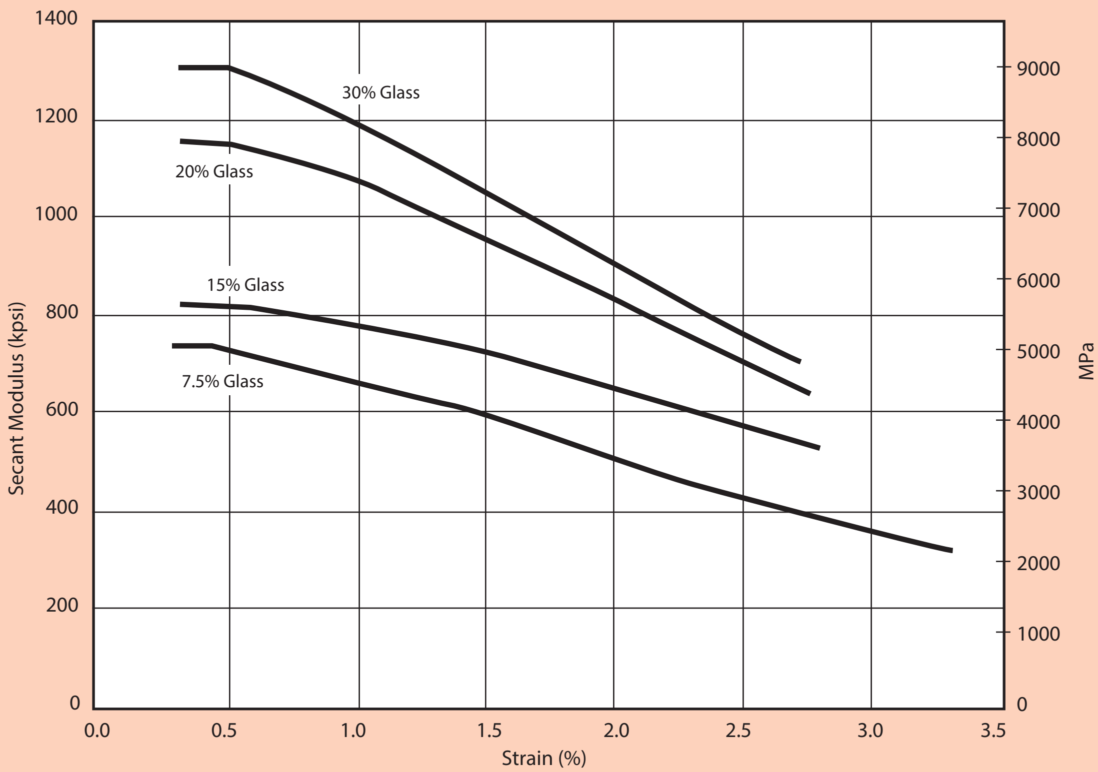


Secant Modulus-Strain Plots

Fig. 2.8 • Typical Tensile Stress and Secant Modulus Plots, 7.5 to 30% Glass Reinforced Grades of Celanex® Thermoplastic Polyester



Tensile Stress-Strain Plots



Secant Modulus-Strain Plots

2

Fig. 2.9 • Typical Tensile Stress and Secant Modulus Plots for Glass and Glass/Mineral Reinforced Grades of Impet® Thermoplastic Polyester

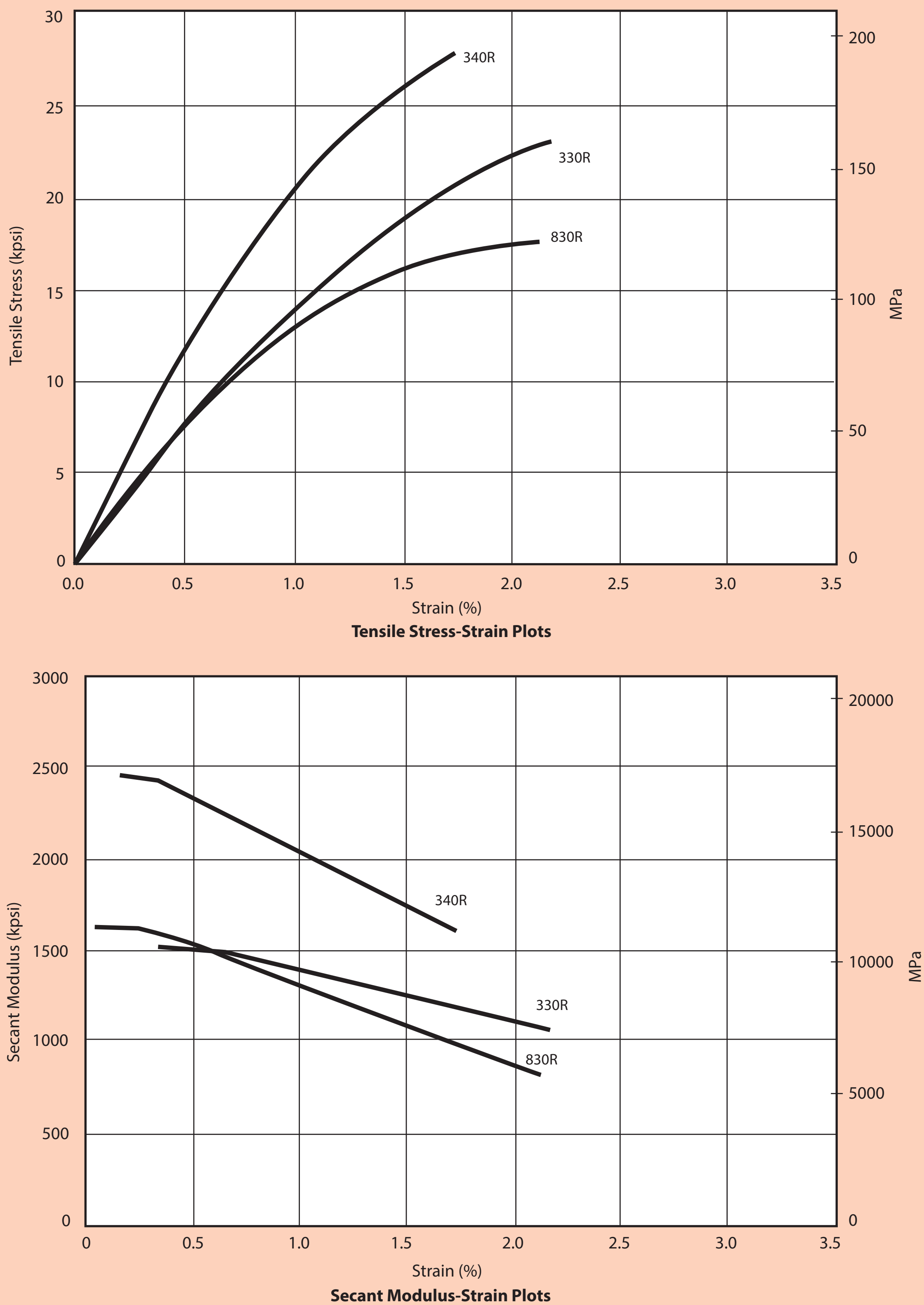


Fig. 2.10 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for Unreinforced Celanex® 2002-2

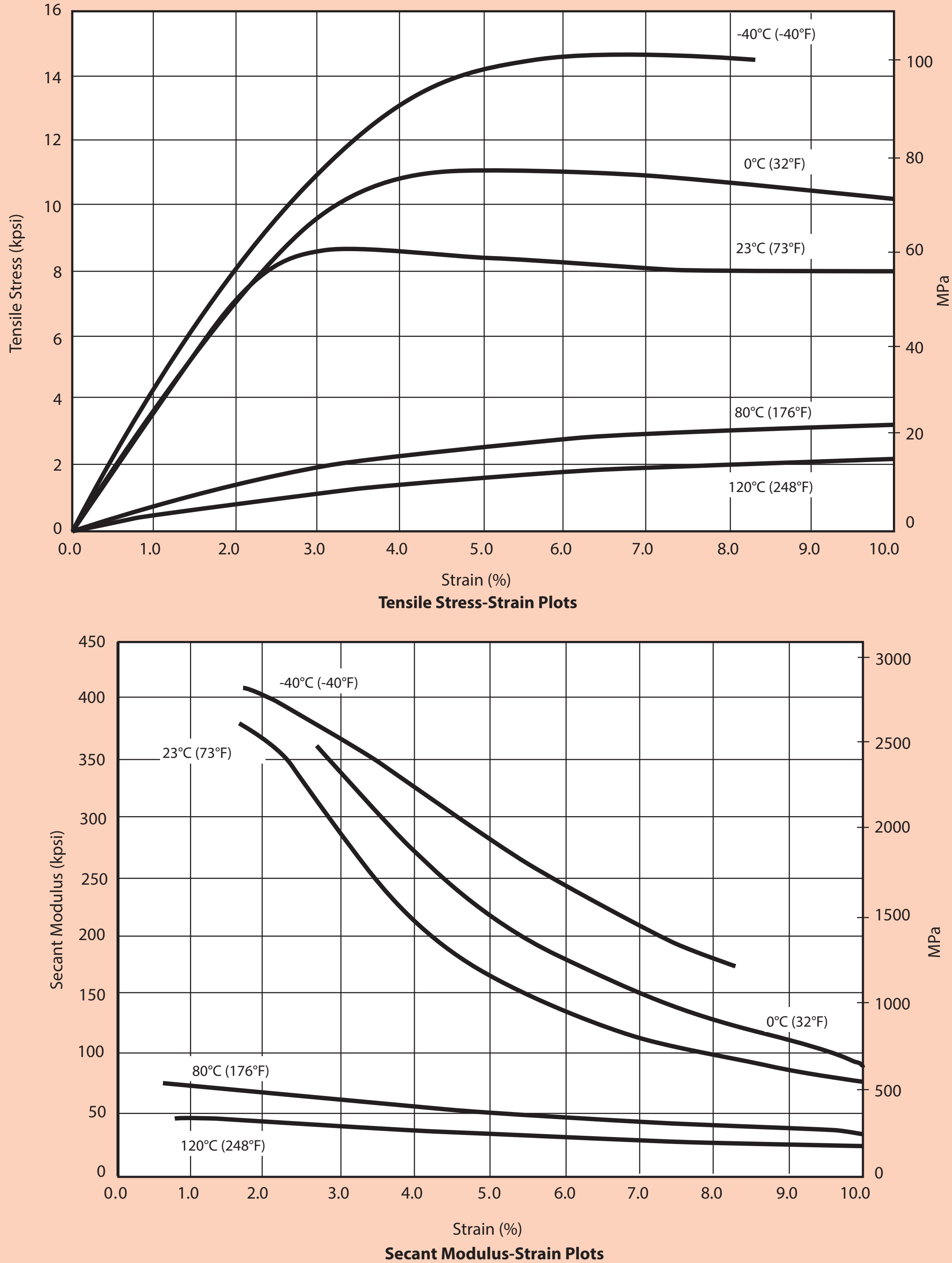


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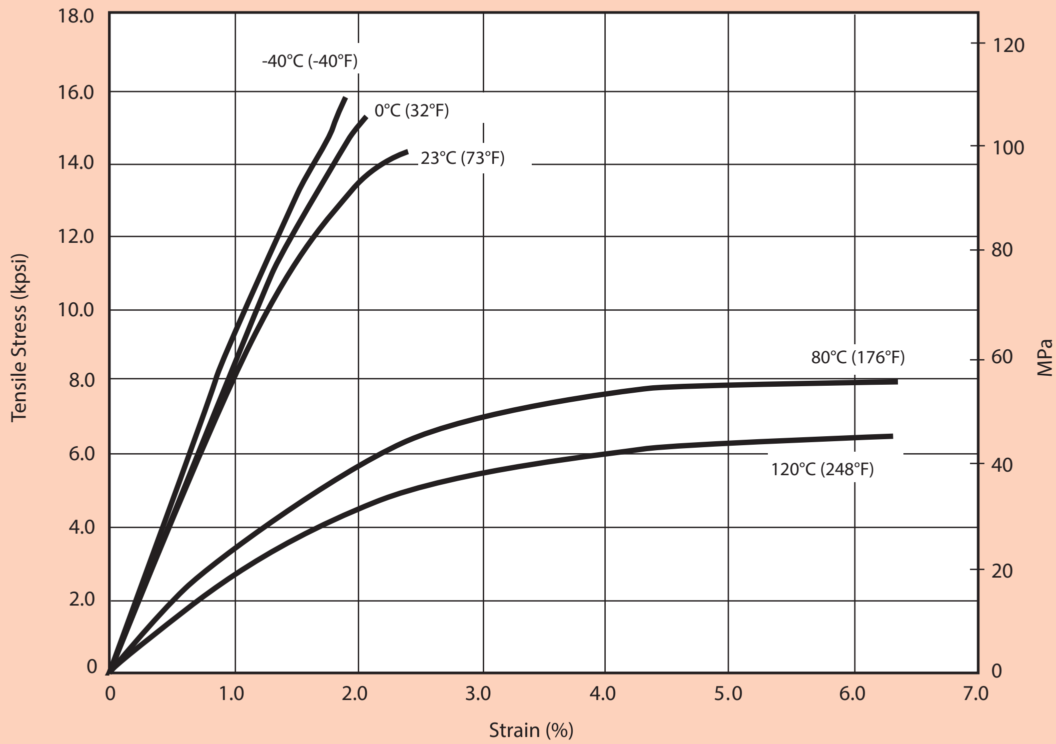
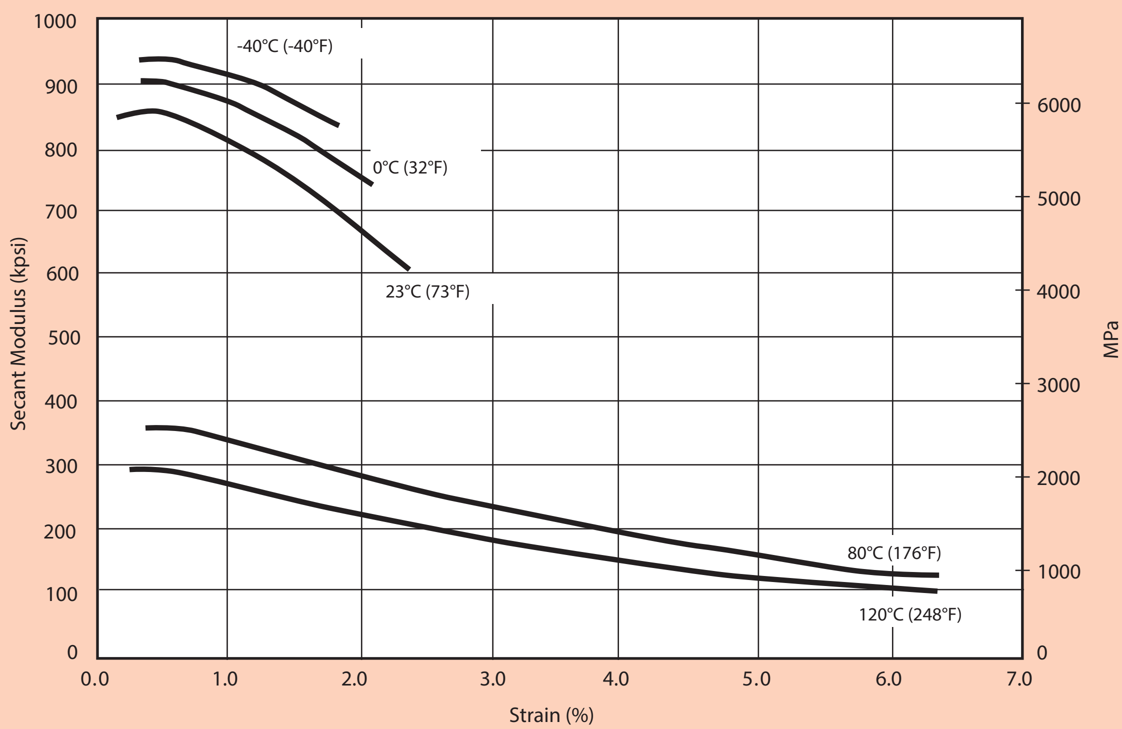
Fig. 2.11 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for 15% Glass Reinforced Celanex® 3200



Tensile Stress-Strain Plots



Secant Modulus-Strain Plots

Fig. 2.12 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for 30% Glass Reinforced Celanex® 3300

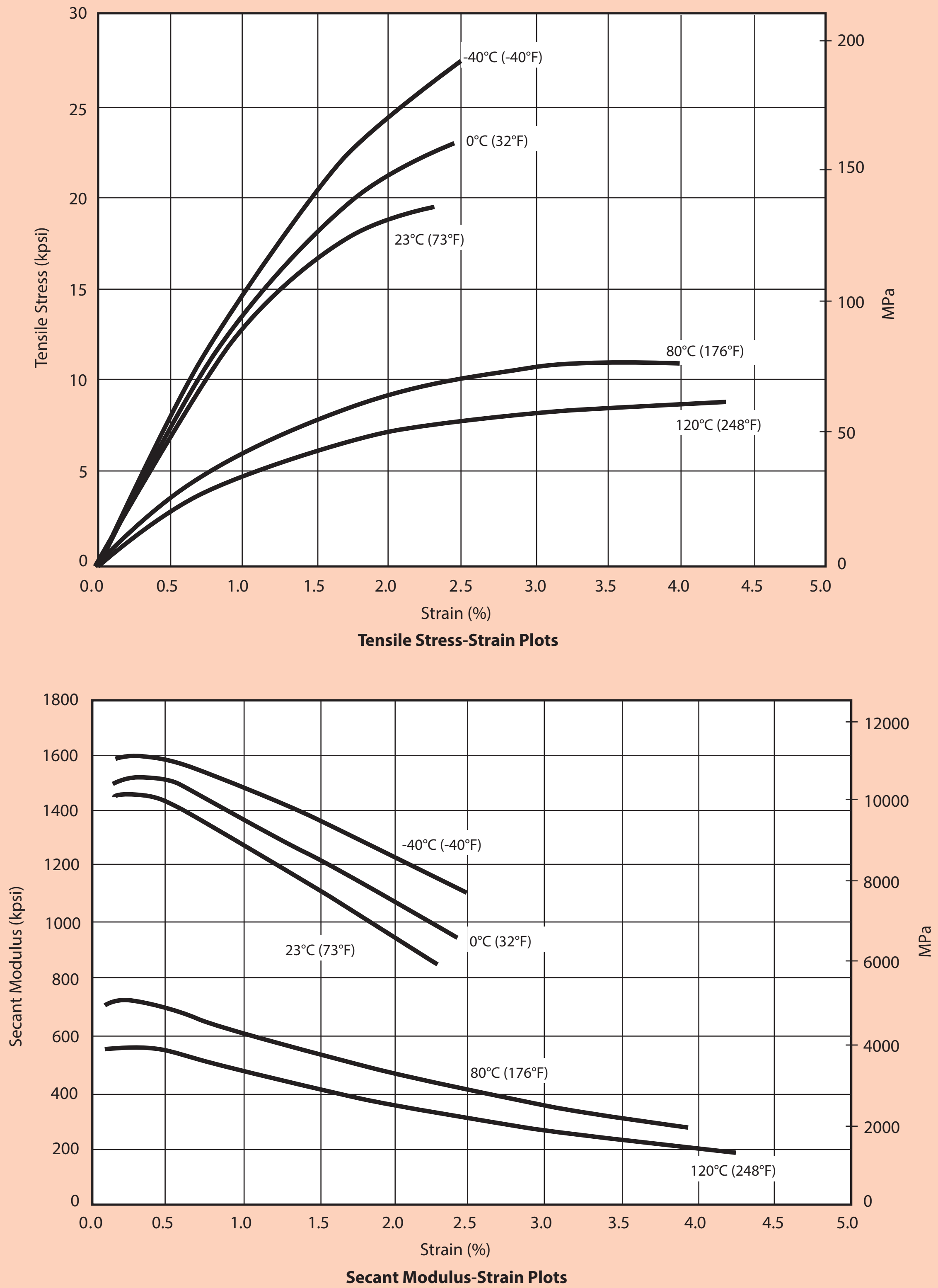


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Fig. 2.13 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Celanex® J600

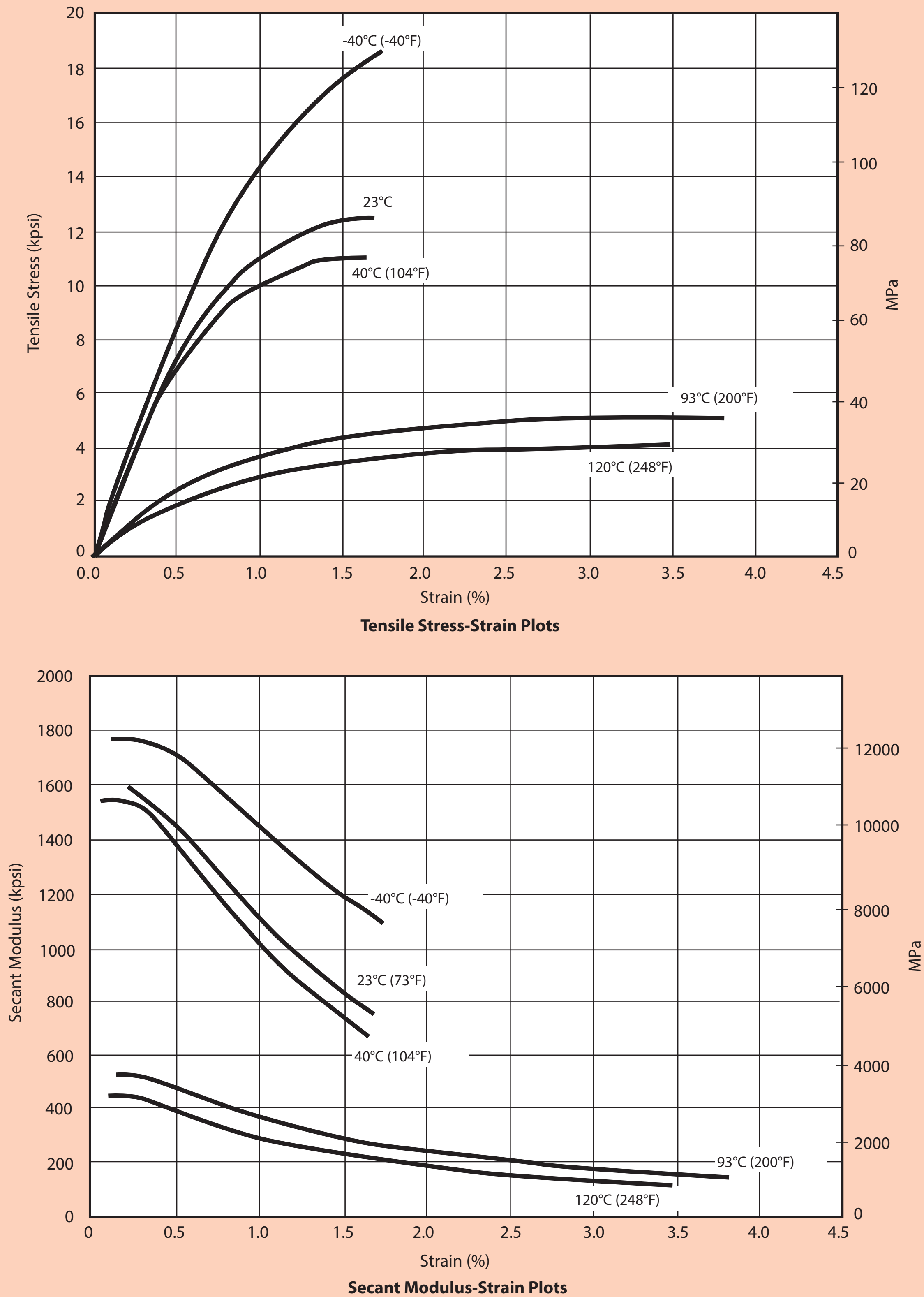
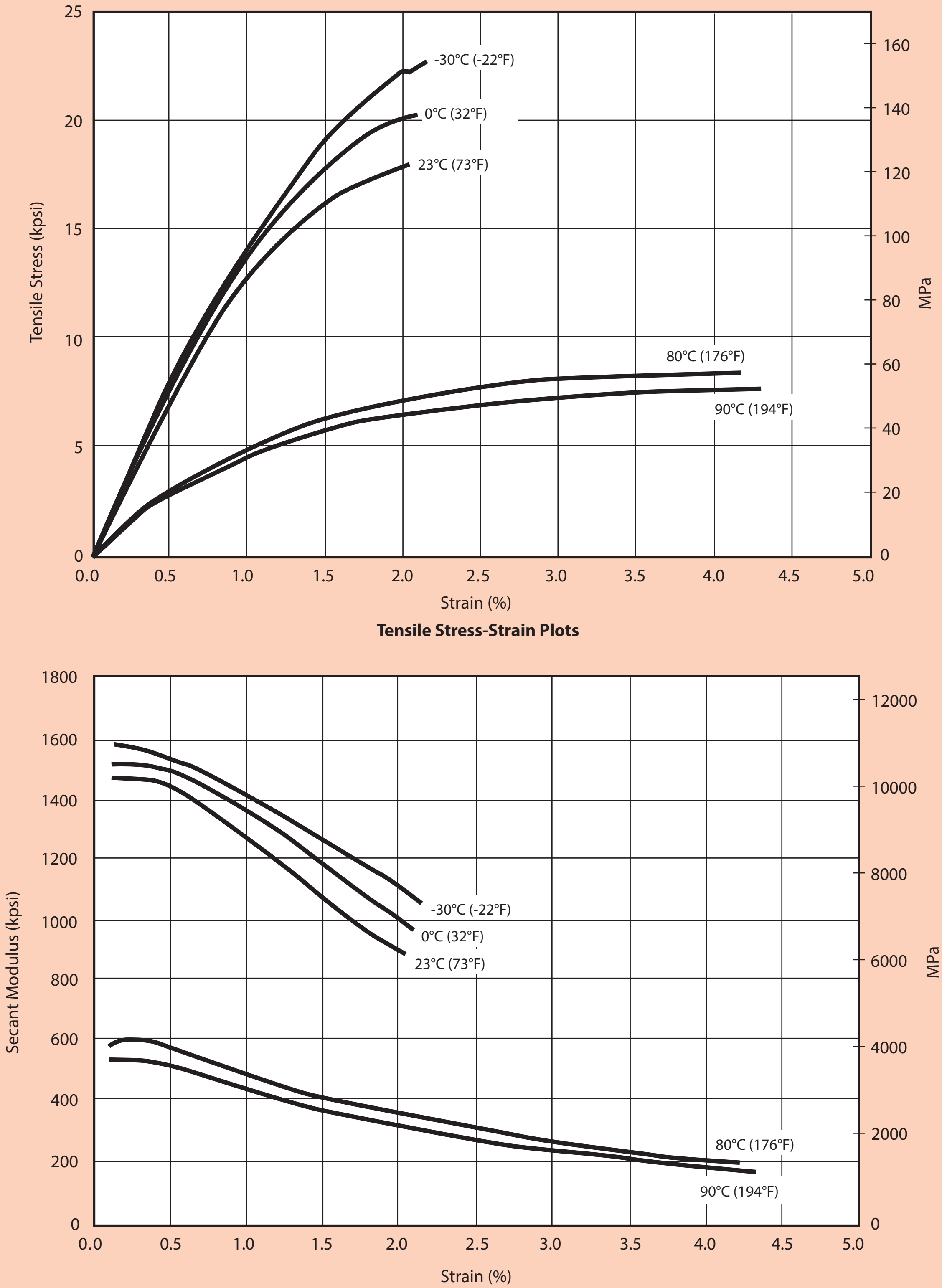


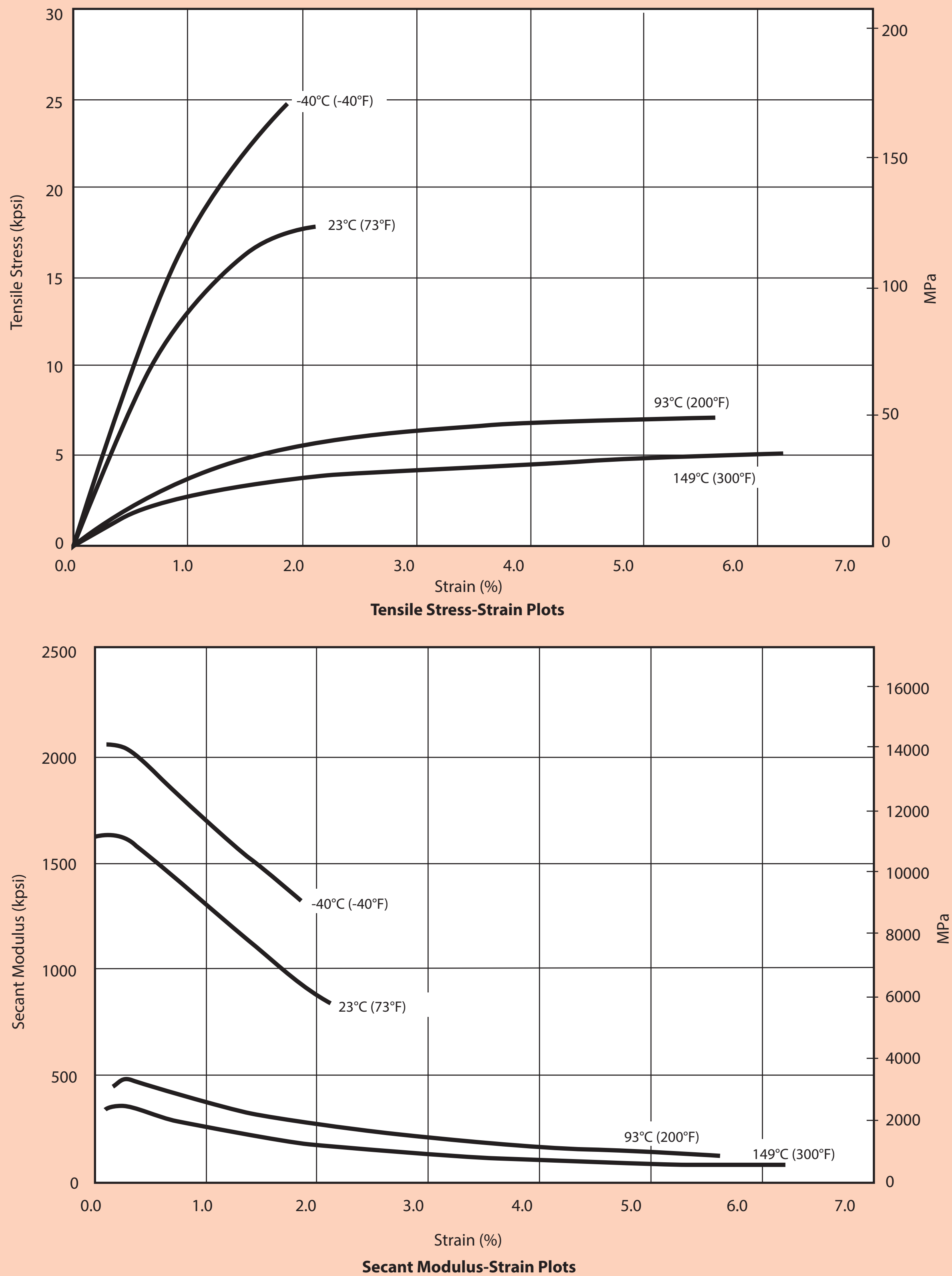
Fig. 2.14 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Celanex® 6500



Tensile Stress-Strain Plots

Secant Modulus-Strain Plots

Fig. 2.15 • Typical Tensile Stress and Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Impet® 830R



2.4 Chemical Resistance

The chemical resistance of a polymeric material depends on the chemical and polymer in question and on the temperature and exposure time as well as on the possible involvement of other factors such as for instance 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.

Semi-crystalline thermoplastic polymers have generally excellent chemical resistance, being dissolved by only a few aggressive organic solvents. Other solvents may cause some swelling as they are absorbed into the amorphous portion of the polymer. Polyesters may also be subject to hydrolysis by extended exposure to high temperature acidic aqueous solutions or attack by strong mineral acids.

Table 2.2 summarizes the results of laboratory testing against many chemicals over a period of 30 days for Celanex® PBT, Impet® PET and Vandar® PBT alloy resins. As with other properties, these data have been determined on standard test bars and may serve as guidelines. The resistance of specific parts to specific chemical environments can only be determined by actual testing. The symbols in the table have the following meanings:

+	Little or no weight change. Resistant.
/	Some change. Limited resistance. Short term exposure possible.
–	Weight change greater than 5%. Property loss. Not recommended.
( )	Used to indicate a different result with glass reinforced versus unfilled Celanex® PBT.
NT*	Has not been tested at this condition.

Table 2.2 • Chemical Resistance of Polyester Resins

Chemical Challenge	PRODUCT FAMILY AND TEST TEMPERATURE					
	Celanex® PBT 23°C	Celanex® PBT 60°C	Vandar® PBT Alloys 23°C	Vandar® PBT Alloys 60°C	Impet® PET 23°C	Impet® PET 60°C
Acetic acid, 5%	+	/	NT*	NT*	NT*	NT*
Acetic acid, 10%	+	/	/	/	+	/
Acetic acid, 100%	–	–	–	–	/	NT*
Acetone	+(/)	–	+	–	/	NT*
Allyl alcohol	+	NT*	NT*	NT*	NT*	NT*
Ammonia, 10%	/	–	/	–	+	NT*
Amyl acetate	+	–	NT*	NT*	NT*	NT*
Benzene	+	–	+	–	+	NT*
Brake fluid	+	+	+	+	+	+
Butane	+	NT*	+	NT*	NT*	NT*
Butanediol-1,4	+	/	NT*	NT*	NT*	NT*
Butanol	+	/	+	/	NT*	NT*
Butyl acetate	+	+	+	+	NT*	NT*
n-Butyl ether	+	NT*	NT*	NT*	NT*	NT*
Calcium chloride, 10%	+	+ (/)	+	+	NT*	NT*
Calcium hypochlorite	+	+	NT*	NT*	NT*	NT*
Carbon disulphide	+	NT*	+	NT*	NT*	NT*
Carbon tetrachloride	+	NT*	+	NT*	NT*	NT*
Chlorobenzene	–	–	–	–	NT*	NT*
Chloroform	–	–	–	–	NT*	NT*
Citric acid, 10%	+	/	+	/	NT*	NT*

Table 2.2 • Chemical Resistance of Polyester Resins

Chemical Challenge	PRODUCT FAMILY AND TEST TEMPERATURE					
	Celanex® PBT 23°C	Celanex® PBT 60°C	Vandar® PBT Alloys 23°C	Vandar® PBT Alloys 60°C	Impet® PET 23°C	Impet® PET 60°C
Cresol	–	–	–	–	NT*	NT*
Detergent, synthetic	+	+ (/)	+	+	NT*	NT*
Dibutyl phthalate	+	/	+	/	NT*	NT*
1,2-Dichloroethane	–	NT*	–	NT*	NT*	NT*
Diesel oil	+	+	+	+	+	NT*
Diethyl ether	+	NT*	+	NT*	+	NT*
Dioxane	+	–	+	–	NT*	NT*
Engine oils	+	+	+	+	+	+
Ethanol	+	/	+	/	+	NT*
Ethyl acetate	+ (/)	–	/	–	/	NT*
Ethylene glycol	+	/	+	/	+	/
Fluorocarbons	+	NT*	+	+	NT*	NT*
Fluorocarbon, HFA134a	+	/	NT*	NT*	NT*	NT*
Fluorocarbon, HFA 227	+	+	NT*	NT*	NT*	NT*
Formic acid, 10%	+	/	+	/	+	NT*
Glycerol	+	+ (/)	+	+	+	NT*
Heptane	+	+	+	+	NT*	NT*
Hexane	+	+	+	+	+	NT*
Hydraulic oil	+	+	+	+	+	+
Hydrochloric acid, conc.	–	–	–	–	NT*	NT*
Hydrochloric acid, 10%	+	/	+	–	+	NT*

Table 2.2 • Chemical Resistance of Polyester Resins

Chemical Challenge	Celanex® PBT 23°C	Celanex® PBT 60°C	Vandar® PBT Alloys 23°C	Vandar® PBT Alloys 60°C	Impet® PET 23°C	Impet® PET 60°C
Hydrofluoric acid, 10%	/ (–)	/ (–)	/	/	NT*	NT*
Hydrofluoric acid, 5%	+ (–)	/ (–)	NT*	NT*	NT*	NT*
Hydrogen peroxide,35%	+	/	NT*	NT*	NT*	NT*
Hydrogen peroxide, 5%	+	/	NT*	NT*	NT*	NT*
Isopropanol	+	/	+	/	+	NT*
Kerosene	+	+	+	+	NT*	NT*
Linseed oil	+	+	+	+	NT*	NT*
Lubricating grease	+	+	+	+	+	+
Methanol	+	/	+	/	+	/
Methyl ethyl ketone	+ (–)	/	+	/	NT*	NT*
Methylene chloride	–	NT*	–	NT*	–	NT*
Mineral oil	+	+	+	+	NT*	NT*
Nitric acid 10%	+	/	+	/	NT*	NT*
Nitric acid, conc.	–	–	–	–	NT*	NT*
Octane	+	+	+	+	NT*	NT*
Olive oil	+	+	+	+	NT*	NT*
Paraffin oil	+	+	+	+	NT*	NT*
Perchloroethylene	/	/	/	–	NT*	NT*
Gasoline, premium	+	/	+	/	+	/
Gasoline, regular	+	/	+	/	+	/
Petroleum	+	+	+	+	NT*	NT*
Phenol, 10%	–	–	–	–	NT*	NT*
Phosphoric acid, 20%	+	/	+	/	NT*	NT*
Potassium chloride, 10%	+	+ (/)	+	+	NT*	NT*
Potassium dichromate, 10%	+	+	+	+	NT*	NT*
Potassium hydroxide,1%	+ (–)	/(–)	NT*	NT*	NT*	NT*
Potassium hydroxide, 10%	/ (–)	–	–	–	–	NT*

Table 2.2 • Chemical Resistance of Polyester Resins

Chemical Challenge	Celanex® PBT 23°C	Celanex® PBT 60°C	Vandar® PBT Alloys 23°C	Vandar® PBT Alloys 60°C	Impet® PET 23°C	Impet® PET 60°C
Potassium permanganate, 10%	+	/	+	/	NT*	NT*
Silicone oils	+	+	+	+	NT*	NT*
Soap solution, 10%	+	+ (–)	+	/	NT*	NT*
Sodium bisulphate, 10%	+	+	+	+	NT*	NT*
Sodium carbonate, 10%	+	+	+	+	+	+
Sodium chloride, 10%	+	+	+	+	NT*	NT*
Sodium hydroxide, 1%	+	/ (–)	NT*	NT*	NT*	NT*
Sodium hydroxide, 10%	/ (–)	–	–	–	NT*	NT*
Sodium hypochlorite, 10%	+	+ (/)	NT*	NT*	NT*	NT*
Sulfuric acid, conc.	–	–	–	–	NT*	NT*
Sulfuric acid, 10%	+	–	+	–	+	NT*
Tetrahydrofuran	/	NT*	–	NT*	NT*	NT*
Toluene	+	–	/	–	+	NT*
Transformer oil	+	+	+	+	NT*	NT*
Trichloroethylene	/	–	/	–	NT*	NT*
Turpentine oil	+	NT*	+	NT*	NT*	NT*
Vaseline	+	+	+	+	NT*	NT*
Vegetable oil	+	+	+	+	NT*	NT*
Washing soap	+	+	+	+	NT*	NT*
Water	+	NT*	NT*	NT*	+	+
Xylene	+	–	/	–	+	NT*

Because of its extensive use in many engineering applications involving potentially challenging chemical environments, glass-reinforced Celanex PBT has also been thoroughly tested under different exposure conditions and careful measurements made on weight change, dimensional stability and tensile strength retention. These results are given in Table 2.3.

Table 2.3 • Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters

Material	Time (Days)	Temperature °C (°F)	% Change Tensile Strength	% Change Weight	% Change Diameter*
ACIDS, BASES AND DILUTE SALT SOLUTIONS					
10% Ammonium Hydroxide	90	23 (73)	-13.0	+0.6	+0.3
	180	23 (73)	-58.0	+0.3	0.0
	360	23 (73)	-73.5	+0.9	+0.6
	9	82 (180)	-92.0	+2.1	+0.3
	24	82 (180)	-99.0	-4.2	+0.1
1% Sodium Hydroxide	90	23 (73)	-47.0	+0.8	+0.6
	180	23 (73)	-72.0	+0.5	+0.1
	360	23 (73)	-84.0	+0.3	+0.7
	24	82 (180)	-96.0	-1.9	0.0
10% Sodium Chloride	90	23 (73)	-6.0	+0.3	+0.2
	180	23 (73)	-6.0	+0.4	+0.2
	360	23 (73)	-4.0	+0.4	+0.2
10% Hydrochloric Acid	90	23 (73)	-4.0	-0.1	+0.2
	180	23 (73)	-12.0	+0.1	+0.1
	360	23 (73)	-20.0	+0.2	+0.1
	24	82 (180)	-24.0	-0.6	0.0
	64	82 (180)	-68.0	-2.4	-0.1
3% Sulfuric Acid	90	23 (73)	-7.0	+0.2	+0.2
	180	23 (73)	-10.0	+0.2	-0.1
	360	23 (73)	-8.0	+0.2	+0.1
	24	82 (180)	-25.0	+0.2	+0.1
	64	82 (180)	-65.0	+0.2	+0.1
40% Sulfuric Acid	90	23 (73)	-2.0	+0.4	0.0
	180	23 (73)	-4.0	+0.0	+0.1
	360	23 (73)	-4.0	+0.1	+0.1
Water (Tap)	90	23 (73)	-5.0	-0.3	+0.1
	180	23 (73)	-3.0	+0.3	+0.1
	360	23 (73)	-5.0	+0.3	+0.1
	60	38 (100)	-3.0	—	—
Buffer, pH 10	90	23 (73)	-6.0	+0.3	+0.1
	180	23 (73)	-9.0	0.0	+0.2
	360	23 (73)	-9.0	+0.7	+0.2
Buffer, pH 4	90	23 (73)	-4.0	+0.3	+0.1
	180	23 (73)	-7.0	+0.3	+0.1
	360	23 (73)	-8.0	+0.4	+0.1
1% Soap Solution	180	23 (73)	-5.0	—	—
	360	23 (73)	-24.0	—	+0.1
Presoak Solution (Axion)	180	23 (73)	-4.0	—	—
	360	23 (73)	-5.0	—	+0.1
Calgon Water Softener Solution	180	23 (73)	-6.0		—
	360	23 (73)	-8.0	—	+0.1
Buffer, pH 7	180	23 (73)	-5.0	+0.3	+0.1
	360	23 (73)	-9.0	+0.3	+0.1
Calgonite Dishwasher Solution	180	23 (73)	-3.0	—	—
	360	23 (73)	-23.0	+1.3	+0.2

* 1/8" thick x 2" diameter disc.

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Table 2.3 • Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters

Material	Time (Days)	Temperature °C (°F)	% Change Tensile Strength	% Change Weight	% Change Diameter*
ORGANIC CHEMICALS					
Laundry Detergent	180	23 (73)	-4.0	—	—
	360	23 (73)	-24.0	—	+0.1
Diethyl Ether	90	23 (73)	-6.0	+0.3	+0.1
	180	23 (73)	-1.0	+0.3	+0.1
	360	23 (73)	-4.0	+0.5	+0.1
5% Acetic Acid	90	23 (73)	0.0	+0.3	+0.2
	180	23 (73)	-5.0	+0.3	+0.1
	360	23 (73)	-5.5	+0.2	+0.2
	30	82 (180)	-41.0	+0.7	+0.2
	60	82 (180)	-77.0	+1.1	+0.2
Benzene	90	23 (73)	-4.0	+0.5	+0.1
	180	23 (73)	-4.0	+0.4	+0.1
	360	23 (73)	-4.0	+0.8	+0.2
	60	49 (120)	-29.0	+4.4	+0.5
	240	49 (120)	-40.0	+5.9	+0.9
Acetone	90	23 (73)	-15.0	+1.0	+0.2
	180	23 (73)	-20.0	+2.0	+0.2
	360	23 (73)	-27.0	+2.4	+0.6
	60	49 (120)	-35.0	+3.4	+0.7
	240	49 (120)	-32.0	+3.6	+0.7
Toluene	90	23 (73)	-8.0	—	+0.1
	180	23 (73)	-7.0	—	+0.1
	360	23 (73)	-8.0	+0.4	+0.1
	24.0	82 (180)	-39.0	+4.3	+0.8
BTX	90	23 (73)	-5.0	+0.4	+0.1
	180	23 (73)	-3.0	+0.5	+0.1
	360	23 (73)	-10.0	—	+0.1
Heptane	90	23 (73)	-4.0	+0.2	+0.0
	180	23 (73)	-4.0	+0.1	0.0
	360	23 (73)	-2.0	—	0.0
	60	82 (180)	-14.0	+0.5	+0.1
	240	82 (180)	-17.0	+0.6	+0.2
Carbon Tetrachloride	90	23 (73)	0.0	+0.1	0.0
	180	23 (73)	0.0	+0.1	0.0
	360	23 (73)	0.0	+0.1	+0.1
95% Ethanol/Water	24	82 (180)	-50.0	+2.4	+0.4
	90	23 (73)	-3.0	+0.2	+0.1
	180	23 (73)	-6.0	+0.3	+0.3
	360	23 (73)	-5.0	+0.4	+0.1
Perchloroethylene	60	82 (180)	-30.0	+6.5	+0.6
	180	82 (180)	-32.0	+6.7	+0.6
Freon 113	51	23 (73)	-1.0	+0.1	0.0
	180	23 (73)	-2.0	-0.1	0.0
	360	23 (73)	-3.0		0.0

*1/8" thick x 2" diameter disc.

Table 2.3 • Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters

Material	Time (Days)	Temperature °C (°F)	% Change		
			Tensile Strength	Weight	Diameter*
AUTOMOTIVE CHEMICALS					
50% Ethylene Glycol/Water	90	23 (73)	-3.0	+0.3	+0.1
	180	23 (73)	-3.0	+0.4	+0.1
	360	23 (73)	-3.0	+0.3	+0.1
Gasoline (Amoco Unleaded)	180	23 (73)	-1.6	+0.2	0.0
	360	23 (73)	-2.2	+0.2	+0.1
	135	60 (140)	-7.4	+1.4	+0.3
	240	60 (140)	-16.4	+1.9	+0.3
Automatic Transmission Fluid (Type B)	180	23 (73)	-1.0	+0.1	+0.1
	360	23 (73)	-3.0	—	+0.1
	30	93 (200)	-31.0	+0.3	0.0
	48	93 (200)	-51.0	+0.4	+0.1
Delco 222 Brake Fluid	180	23 (73)	+1.0	0.0	0.0
	360	23 (73)	-1.0		+0.1
	30	93 (200)	-43.0	+2.0	+0.3
	48	93 (200)	-60.0	-2.2	+0.4
Motor Oil (10W-40)	180	23 (73)	-3.0	+0.1	+0.1
	360	23 (73)	-3.0	—	+0.1
	60	93 (200)	-43.0	+0.2	0.0
	100	93 (200)	-61.0	+0.2	-0.1
Lubricating Grease	180	23 (73)	-6.0	—	+0.2
	360	23 (73)	-4.0	+0.1	+0.1
	60	93 (200)	-34.0	+0.1	-0.1
	100	93 (200)	-64.0	+0.3	-0.1
Hydraulic Fluid (Skydrol 500B)	180	23 (73)	0.0	0.0	0.0
	360	23 (73)	-4.0	+0.1	+0.1
	60	93 (200)	-34.0	+0.1	-0.1
	240	82 (180)	-5.5	+0.5	+0.1
Turbine Lubricating Oil (Texaco Sato 15)	180	23 (73)	-0.5	-0.1	+0.1
	360	23 (73)	-17.3	—	+0.1
Houghton-Cosmolubric 2425	180	23 (73)	+1.0	0.0	0.0
	360	23 (73)	-16.7	—	0.0

* 1/8″ thick x 2″ diameter disc.

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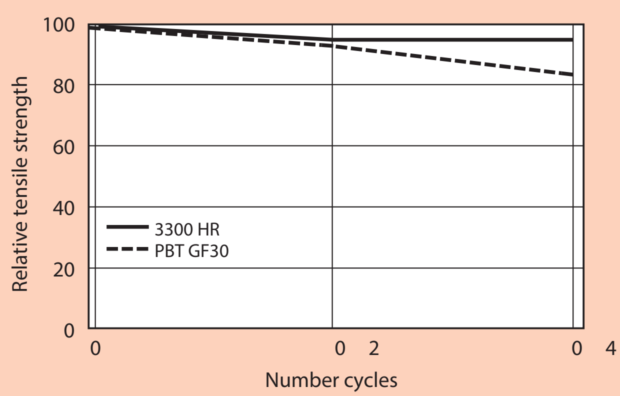
2.4.1 Application-related Chemical Testing

As well as the tests summarized in Tables 2.2 and 2.3, other chemical exposure tests directed toward specific end-use areas have also been carried out. Celanex® PBT resins have been shown to withstand short-term exposure to steam and water under pressure at temperatures up to 150°C. For long-term hot water exposure of both Celanex PBT and Vandar® PBT alloys a temperature limit of 40°C should be observed. Impet® PET resins should not be used in applications requiring prolonged exposure to hot water. Celanese's Celcon® acetal copolymer is recommended where continuous hot water use is expected.

Thermal shock tests at high relative humidity (RH) are important qualification criteria for the automotive industry. The U.S. Council for Automotive Research (USCAR) test calls for finished components to be subjected to 40 temperature and humidity cycles reaching up to 95% RH, after which the component is tested for mechanical and electrical performance. Parts made from standard PBT resins usually meet the requirements for lower temperature classes (up to 80°C and up to 100°C). The Celanex hydrolyis-resistant portfolio is currently the most extensive in the market.

Fig. 2.16 • Change in the Tensile Strength at Break of Celanex® Specimens Tested According to USCAR Class III



Very short term exposures (such as for example temporary surface wetting) of Celanex PBT parts shows excellent resistance to chemicals likely to be found in the automotive environment including gasoline, engine oil, transmission fluid, brake fluid, engine coolant and windshield washer solution. Except for battery acid, no surface damage to parts is observed even in a 5 cycle test requiring wetting followed by 48 hours storage at 80°C. Satisfactory performance in this test is found even for engine coolant, an aqueous solution of ethylene or propylene glycol to which polyester resins are not resistant in high temperature continuous exposure. As shown in Table 2.4, no significant change was seen in strength and elongation of 30% glass-reinforced PBT (Celanex PBT 3300) after an ethylene glycol dip followed by six months of hot air exposure at 120°C.

Table 2.4 • Ethylene Glycol Dip Test – 30% Glass Filled PBT

Time (Days)	Tensile Strength MPa (psi)	% of Elongation
Exposure Conditions – Immersed in Ethylene Glycol at 120°C (248°F)		
0	125 (18,200)	3.0
16	29 (4,270)	0.5
Exposure Conditions – Dipped in Ethylene Glycol at 23°C (73°F). Exposure to circulating air at 120°C (248°F)		
0	125 (18,200)	3.0
16	134 (19,500)	2.0
177	122 (17,800)	2.0

2.4.2 Chemical Stress Cracking

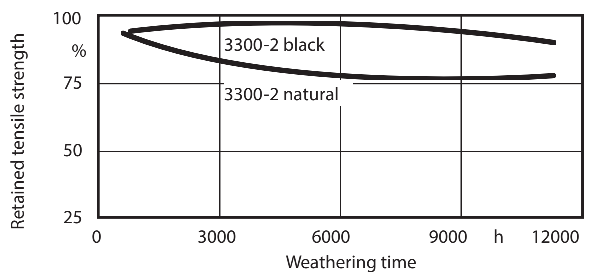
Semi-crystalline resins such as polyesters are generally not susceptible to environmental stress cracking such as affects many amorphous resins under certain conditions. After a 5-hour exposure to different automotive chemicals, no surface cracking was detectable in stressed test specimens of Celanex PBT 3300-2 even under 30x magnification. The test conditions and results are shown in Table 2.5. Electrical engineering components are sometimes exposed to the oxidative attack of ozone generated by arcing. Celanex PBT 3300-2 has been shown to retain 70% tensile impact strength after 50 hours at 121°C (250°F) in an atmosphere containing 1.7% ozone.

Table 2.5 • Stress Cracking Resistance of Celanex® 3300-2

Fiber Stress, MPa	Temperature, °C	Chemical	Time, hr.	Effect
82.8	60	Test Fuel C (ASTM D471), 50% isooctane/50% toluene	5	None
82.8	93	Ethylene Glycol	5	None
82.8	93	Gear Oil A	5	None
82.8	60	Lockheed Heavy Duty Brake Fluid	5	None
82.8	93	Uniflo Oil	5	None
82.8	23	BTX, 50% benzene/37.5% toluene/12.5% xylene	5	None
82.8	23	Skydrol Hydraulic Fluid	5	None

As molding conditions can affect the surface quality and total crystallinity of parts, the test results given above are indicative and should in all cases be verified by testing of actual production parts in the target. A part with poor surface quality made from a glassreinforced material may exhibit susceptibility to wicking of some chemicals along glass fibers exposed at the surface. Such wicking may have an adverse effect on the reinforcement capability of the glass fiber, leading to lower mechanical properties in the part. If small parts made from Impet® PET are molded cold, crystallinity may be reduced and susceptibility to chemical effects increased.

Fig. 2.17 • Effect of Accelerated Weathering in the Weatherometer on the Change in Tensile Stress at Break of Celanex® 3300-2 Black and Natural



2.5 Other Environmental Considerations

Beyond the immediate chemical environment, other factors may affect the properties of plastic parts over time, particularly radiation and weathering. Celanese's polyester resins generally have relatively good resistance to higher energy ionizing radiation, with degradation of a more serious nature not being observed below an absorbed energy level of about 100 kJ/kg. Less intense radiative attack such as solar ultraviolet (UV) is well withstood by the polyesters, although best results are obtained by the use of UV stabilizers, black dyes and particularly carbon black pigments. As shown in Figures 2.17, 2.18 and 2.19, Weatherometer and outdoor exposures show very good retention of strength and impact resistance for Celanex® 3300-2 in both black and natural color.

Fig. 2.18 • Tensile Stress at Break of Celanex® 3300-2 Black and Natural as a Function of Outdoor Weathering Time, Measured in Florida and Arizona

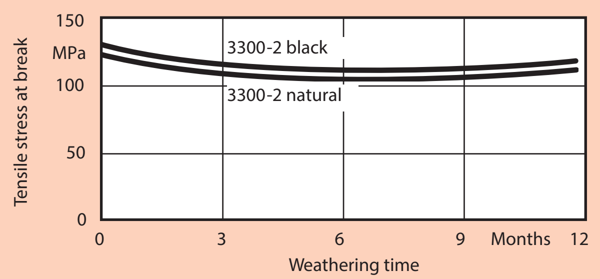
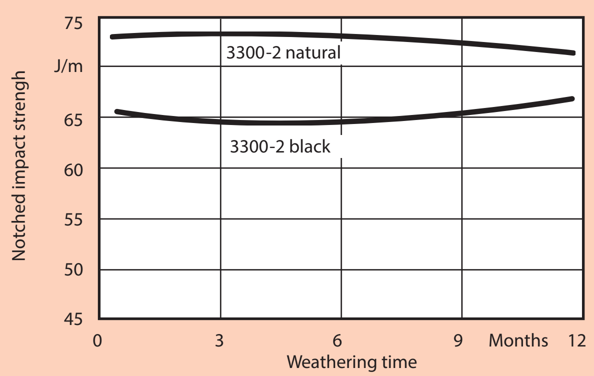


Fig. 2.19 • Notched Impact Strength (Izod) of Celanex® 3300-2 Black and Natural as a Function of Outdoor Weathering Time, Measured in Florida and Arizona



Xenon Arc testing of end-user automotive exterior parts made from other grades also demonstrates good retention of surface quality and mechanical properties. Tables 2.6 and 2.7 show the results of testing done on actual parts according to Society of Automotive Engineers (SAE) standard J1960. Color difference and gloss effects after xenon arc exposure of 2500kJ/m2 are given in Table 2.6 while mechanical property effects are given in Table 2.7.

Please consult Celanese's Product Information Services for more specific information on weatherable grades of Celanex® PBT, Impet® PET and Vandar® PBT alloys.

For automotive interior use, UV-stabilized Celanex PBT and Vandar PBT alloy grade are available as olormatched formulation for applications such as seat belt buckles, door handles and knobs/levers, among others.

Table 2.6 • Prototype Parts Xenon Arc; 2500 kJ/m²; SAE J1960 – Color Difference and Gloss

Celanex® Grades	Part Description	Surface	Condition	DL*	Da*	Db*	DE*
6500 BK225	F-Car Wiper Airfoil	Textured	As Is	-1.96	0.27	1.61	2.55
			Washed	1.70	-0.01	0.27	1.72
			Washed & Polished	0.16	0.02	0.32	0.36
2002-2 ED3807	F-Car Wiper Cover	Textured	As Is	0.87	-0.73	2.50	2.82
			Washed	3.77	-0.06	0.16	3.77
6407 ED3807	Luggage Rack Rail	Smooth	As Is	0.15	0.19	0.77	0.81
			Washed	-0.81	-0.49	-0.01	0.94

Table 2.7 • Mechanical Property Retention After Exposure – Xenon Arc; 2500 kJ/m²; SAE J1960

Properties	Units	Celanex 6500 BK225	Celanex 6407 ED 3807
Tensile Strength @ Break	%	97	97
Elongation @ Break	%	94	93
Notched Izod	%	102	89
Flexural Strength	%	94	92
Flexural Modulus	%	101	100

2.6 Time-dependent Mechanical Properties

2.6.1 Static Stress

Long Term Mechanical Properties

Adequate consideration of long term loads, especially based on creep and stress relaxation, is critical to the design of parts made from thermoplastic polyesters. This can avoid such issues as incorrect estimates of in-use performance capability, part warranty and loss of customer satisfaction.

Fatigue effects, usually considered by parts designers, must be carefully addressed to properly model the real end-use environment. Improperly designed tests can produce erroneous results which may be artifacts and may not reflect real end-use performance.

Creep

The instant any material (including metals) is loaded, it begins to creep. The viscoelastic properties of plastics require that creep behavior be considered, even for room temperature plastics parts design.

When dealing with creep, several points should be considered. Often, parts are subjected to relatively low loads where deflection is a factor but stress is not. In other cases, the primary concern is mechanical failure of the part under long term loads with minimum consideration of deflection. Deflection recovery after removal of long term loads is important in some applications. In general, semicrystalline polyesters withstand creep stress better than amorphous resins. Glass reinforcement generally improves the creep resistance of a plastic material.

Creep Deflection

Creep modulus may be substituted for flexural or tensile modulus in standard equations of linear elasticity used in engineering design. Typical creep modulus curves (at different temperatures) for glass and glass/mineral reinforced grades of Impet are shown in Figure 2.20.

There is considerable variation in creep deflection of plastic assemblies in actual end-use. This is due to variations in wall thicknesses, dimensional variations and material property variability in the molded parts. To compensate for these factors, use a safety factor of 2 whenever creep deflection is important in the end-use application.

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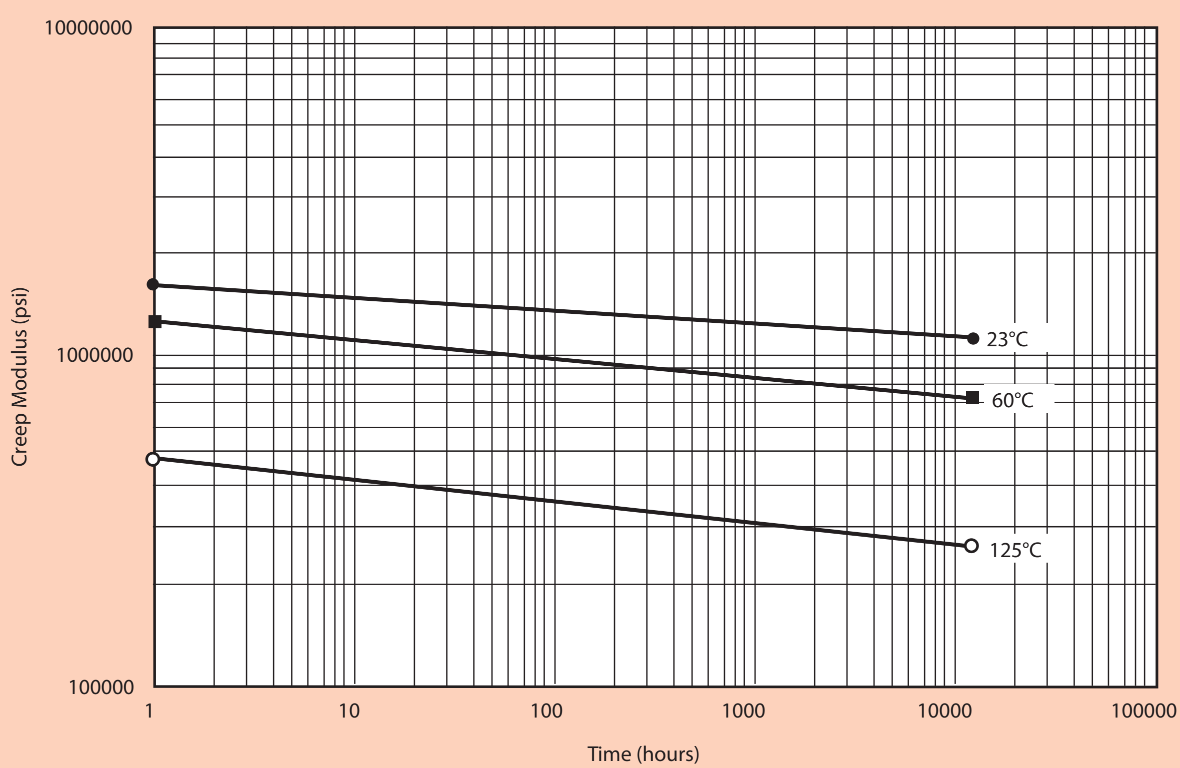
Fig. 2.20 • Flexural Creep Modulus for Glass/Mineral Reinforced Impet® 330R at 4,000 psi



Creep Resistance

Glass reinforced Celanex® resins demonstrate outstanding flexural creep properties. Because of their extremely low moisture absorption and high rigidity, very little creep is experienced at room temperature. Creep resistance at elevated temperatures up to 180°C (356°F) and under heavy loads (2000 psi) is also excellent.

Figure 2.21 shows creep results when tested by ASTM methods which call for 24-hour conditioning at test temperatures before applying the load. Figures 2.22 through 2.24 show creep results when test bars are pre-loaded at room temperature and then immediately brought up to test temperature.

Relaxation

Stress relaxation is similar to creep. In creep, a constant stress is imposed and the strain gradually ncreases. When a constant strain is imposed, there is an initial stress which gradually decays or relaxes with time. Relaxation data are not as common as creep data. Fortunately, creep data give a good approximation of the relaxation phenomenon.

Fig. 2.21 • Flexural Creep at 105°C for Glass Reinforced Celanex® 3300

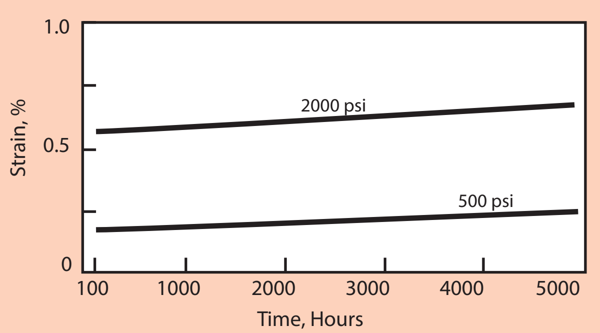


Fig. 2.22 • Flexural Creep at 500 psi Maximum Stress for Glass Reinforced Celanex® 3300

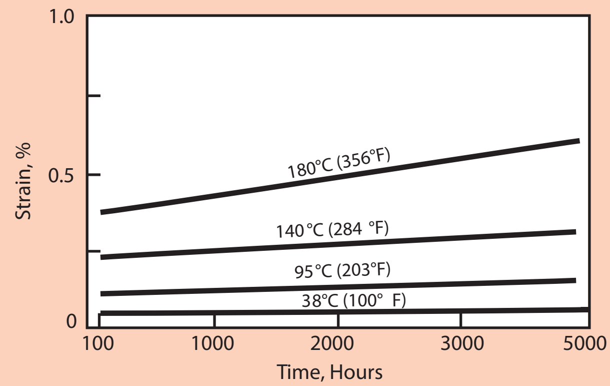


Fig. 2.23 • Flexural Creep at 2000 psi Maximum Stress for Glass Reinforced Celanex® 3300

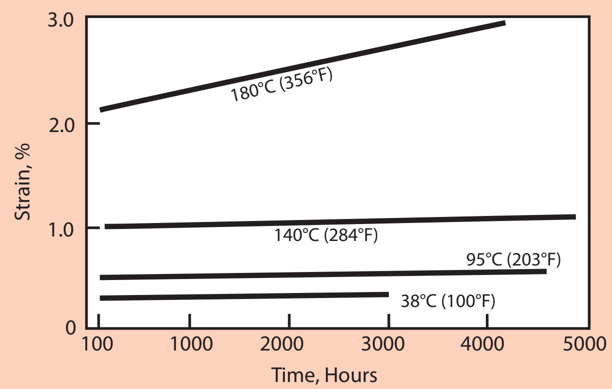
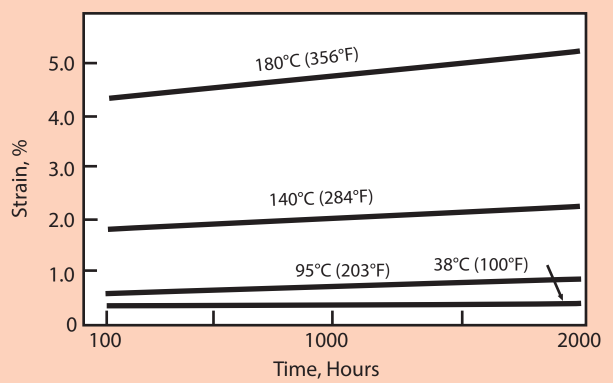


Fig. 2.24 • Flexural Creep at 2000 psi Maximum Stress for Glass Reinforced Celanex® 3200



2.6.2 Fatigue

Fatigue strength is highly dependent on design geometry, processing conditions, temperature and environmental exposure. In addition, the nature of the load influences the fatigue performance. Harmonic, square wave, saw tooth or pulse loading can have very different effects on plastic fatigue.

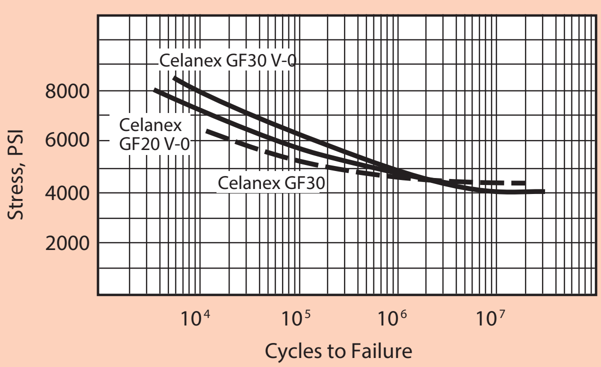
Plastics can also fail in fatigue due to hysteresis heating and deformation rather than the fatigue cracking typically expected.

Figure 2.25 shows fatigue curves for various glass reinforced grades of Celanex® tested according to ASTM D 671. This test involves a beam with a uniform taper (constant stress beam) under harmonic excitation. Since actual end-use conditions may deviate considerably from laboratory test conditions, these fatigue curves should be used as starting points.

Laboratory fatigue testing should be used only as a guide. For example, harmonic excitation is typically used in laboratory testing. The end-use environment may be a saw tooth or pulse loading. These loadings could produce a very different response resulting in either a shorter or longer life than that predicated by laboratory testing.

End-use tests, run continuously to achieve required life cycles, often overheat the test part. This results in lower fatigue life than the part might have in the intermittent and/or lower temperature end-use environment. Alternatively, an accelerated fatigue test run at a controlled, elevated temperature to model enduse environment, may overestimate the fatigue performance of the part by failing to consider aging effects at elevated temperature.

Fig. 2.25 • Flexural Fatigue Plot for Various Glass Reinforced Grades of Celanex® Thermoplastic Polyester



2.7 Surface Properties

Molded parts of both Celanex® PBT and Impet® PET have hard surfaces, particularly when glass reinforced. Table 2.8 shows the increase in ball indentation hardness achievable in these materials with high levels of glass reinforcement.

Both Celanex PBT and Impet PET exhibit low sliding friction against steel. The dynamic coefficient of friction of unreinforced Celanex PBT against steel lies between 0.2 and 0.45 depending on surface pressure loading and sliding speed. However, because softening of PBT polymer starts around 50°C, slide bearing design should be based on an appropriately low pressure velocity (PV) value. Under such conditions, Celanex PBT polymers have low wear against steel. Similar good results can be achieved with glassreinforced grades, provided that they are molded so as to have a resin-rich surface. Properly molded Celanex PBT parts also exhibit excellent frictional properties against part made from Celcon® polyacetal resins.

Celanex PBT and Impet PBT offer particularly good surface properties, such as hardness, abrasion resistance and low friction, which are important for many technical applications.

Hardness

For thermoplastics, it is customary to determine ball indentation hardness in accordance with ISO 2039, part 1. Ball indentation hardness is temperaturedependent and for the Celanex general-purpose grades lies between 122 and 145 N/mm2 at 23ºC and 358 N test load.

Table 2.8 • Ball Indentation Hardness of Polyesters, 23°C, 358N Load

Celanex® PBT Fiberglass Level	Celanex® PBT Hardness	Impet® PET Fiberglass Level	Impet® PET Hardness
0%	122-145 N/mm^2	0%	
50%	235 N/mm^2	45%	300 N/mm^2

Glass-fiber-reinforced Celanex PBT 2300 GV 1/50 attains 235 N/mm^2 and Impet PBT 2700 GV 1/45 even reaches 300 N/mm^2.

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Low-friction properties

Celanex PBT and Impet PBT both have good low-friction properties similar to those of Celcon®/Hostaform® acetal copolymer.

The dynamic friction coefficient of unreinforced Celanex PBT 2500 in sliding contact with steel lies between 0.2 and 0.45, depending on surface pressure loading p and sliding speed v. However, because the softening range of Celanex PBT starts at 50ºC, the p · v value used in the design of slide bearings is lower than for Hostaform acetal copolymer. For this reason, the glass-fiber-reinforced products are normally used if relatively high operating temperatures – due to frictional heat or the ambient temperature – are expected. This is possible because in injection molding – assuming high mold cavity temperatures – a surface layer with low glass fiber content and good friction properties is formed.

If – after prolonged periods of service – glass fibers are exposed in the sliding surface, stick slip and noisy operation must be expected with Celanex PBT in sliding contact with steel. Glass-sphere-filled products behave in a similar way to the glass-fiberreinforced grades and offer no advantages in terms of noise development.

Wear of Celanex® PBT

Unreinforced Celanex PBT has good wear properties if surface pressure p and sliding speed v are limited to values that preclude a noticeable increase in sliding surface temperature. Generally speaking, PBT is regarded as suffering somewhat greater wear in contact with smooth steel shafts (RZ << 2 µm) and somewhat less wear in contact with rough steel shafts (RZ > 2 µm) than POM, Figure 2.26. In tests with the pin/shaft system in contact with steel (RZ = 0.8 µm) both the unreinforced Celanex PBT 2500 and some glass-fiberreinforced Celanex grades showed higher wear resistance than unmodified Hostaform® acetal copolymer C 9021, see Figure 2.27.

For information and/or recommendations on polyester gear and bearing design criteria and on special wear resistant grades, please consult Celanese's Product Information Services at 1-800-833-4882, prodinfo@celanese.com, or as shown on the back cover of this brochure.

Fig. 2.26 • Typical behavior of some unfilled thermoplastic polymers when used in plain bearings sliding at low velocity against steel, without lubrication (relative comparison)

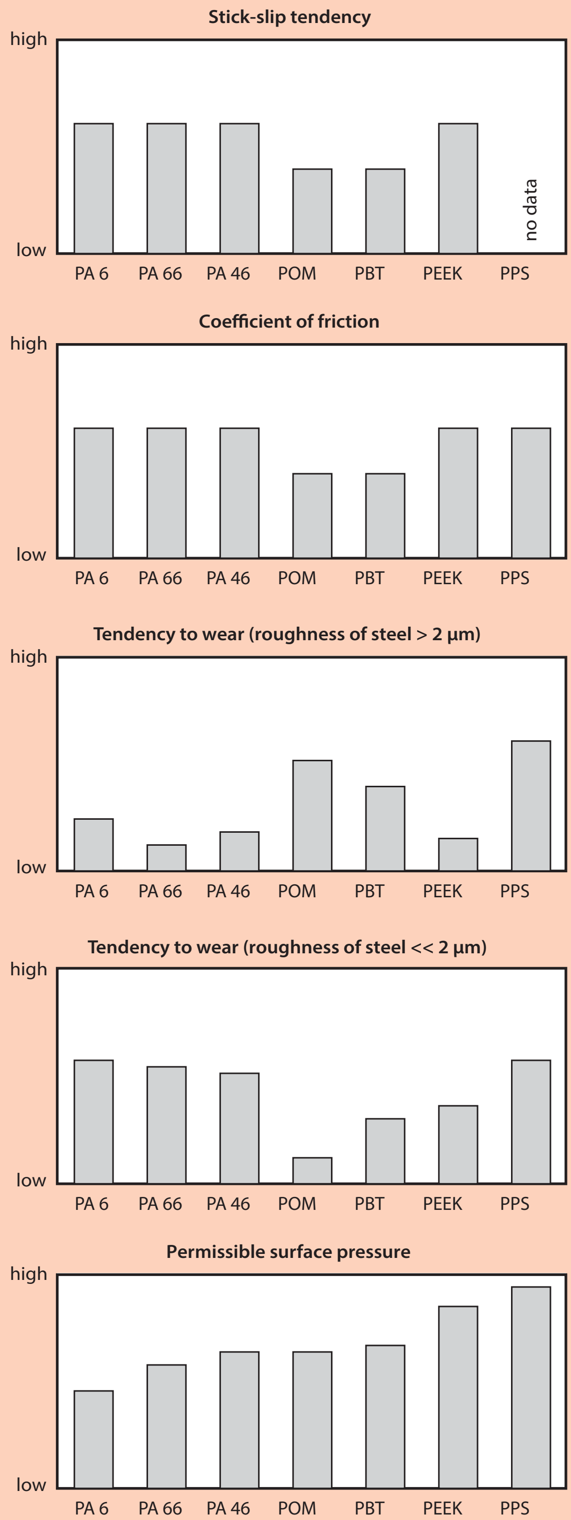
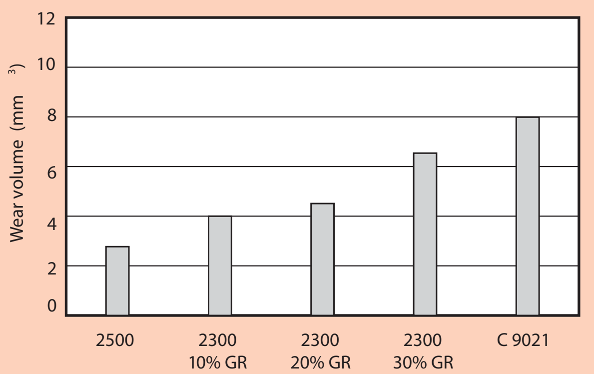


Fig. 2.27 • Wear properties of various Celanex® PBT grades compared with Hostaform® acetal copolymer in dry sliding contact; pin/shaft system in contact with steel (RZ = 0.8 µm, v = 136 m/min., F = 3 N, test duration 60 h.)



2.8 Thickness and Time Dependence of Electrical Properties

The generation of internal electrical stress is affected by part homogeneity. In general, the thicker a part, the more susceptible it is to microvoiding and the localization of high dielectric stress at those points. As a result, dielectric strength diminishes with increasing part thickness as shown in Figure 2.28 for Celanex® PBT grades 3300 and 5300.

Although polyesters are not hygroscopic, they do absorb a small amount of moisture after extended humidity exposure. That this does not significantly impair insulating properties is shown for Celanex PBT 3300 in Figure 2.29. Resistance to dielectric breakthrough is also well sustained under high temperature exposure with more than 50% being retained even after four months at 170ºC as shown in Figure 2.30.

Fig. 2.28 • Dielectric Strength Versus Thickness, Reinforced Grades of Celanex® Thermoplastic Polyester

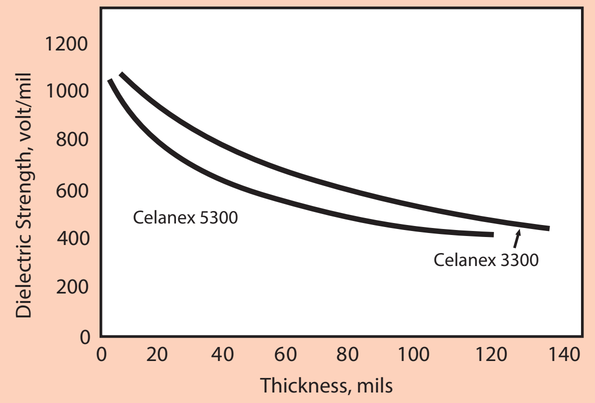


Fig. 2.29 • Volume Resistivity of Reinforced Grades of Celanex® Thermoplastic Polyester as a Function of Time at 70°C (158°F) and 100% Humidity

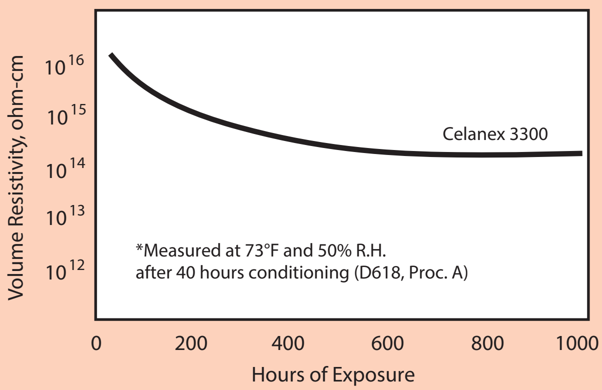
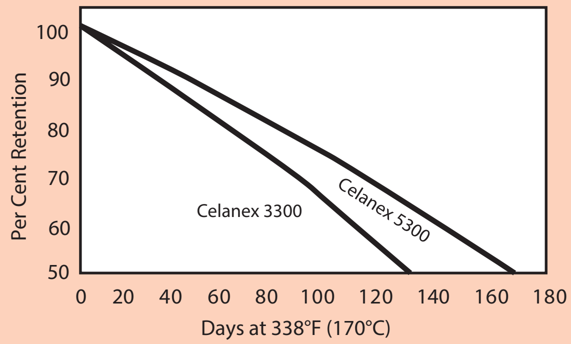


Fig. 2.30 • Heat Aging Effects on Dielectric Strength, Reinforced Grades of Celanex® Thermoplastic Polyester – 0.8 mm Thickness



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3. Processing

3.1 General

Celanese's thermoplastic polyesters are typically processed not only by injection molding and related methods, but also by various other extrusion-related processes. Among the latter may be counted profile and tube extrusion, monofilament extrusion, melt blowing and other fiber-oriented processes.

Processing conditions are determined in a general way by the chemistry of the base polymer such that process temperatures for Impet® PET resins are commonly higher than those for Celanex® PBT resins. Vandar® PBT alloy processing conditions are somewhat more grade-driven, being influenced by the specific components of each alloy grade. However, beyond these broad prescriptions, general processing and handling procedures are similar, differing more in degree than in kind.

3.1.1 Resin Storage

Resin should be stored so as to 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. Because the large surface area of regrind can facilitate moisture pickup, proper storage is essential for reground material intended for re-use. In any case, both virgin and reground materials must be dried to the recommended moisture levels before processing begins. Proper drying is important for all polyester resins, but crucial for Impet PET grades.

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 be properly dried together with the virgin resin before processing. For certain grades of Celanex PBT, performance in conformity with Underwriters Laboratory (UL) standards has been demonstrated at the 50% regrind level. This attribute is particularly valuable where small parts are being molded with a relatively large portion of the total shot volume going into sprues and runners.

3.1.3 Ventilation

The overall processing area should be adequately ventilated. Exhaust vents should be located over molding machines or extruders, preferably close to the nozzles or dies, to remove any gas or dust. Vented air quality should be in compliance with applicable State and Federal regulations.

3.1.4 Startup and Shutdown

Before feeding any polyester resin to the processing equipment, the machine should be adequately purged to remove any other type of plastic previously run on it. Feed lines should also be thoroughly cleaned. Suitable purge materials include polyethylene, polypropylene and polystyrene. For parts intended for subsequent painting, 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 actual grade that is to be run.

When a machine is being shut down after processing a polyester 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 only the polyolefin purge material issues from the nozzle or die.

3.1.5 Changing Feedstocks

Somewhat different processing temperatures may be required for different polyester resins. For example, Impet PET materials have higher melting temperatures than the various Celanex PBT grades and so will usually need to be processed at higher machine temperatures. To change from one of Celanese's polyester products to another, machine settings should if necessary be adjusted to the proper levels for the new grade and the process then run for a sufficient time for the melt inventory to be converted to the new material. If the material change is to a different (non-polyester) resin, the machine should be fully purged as described in paragraph 3.1.4 before introduction of the new material.

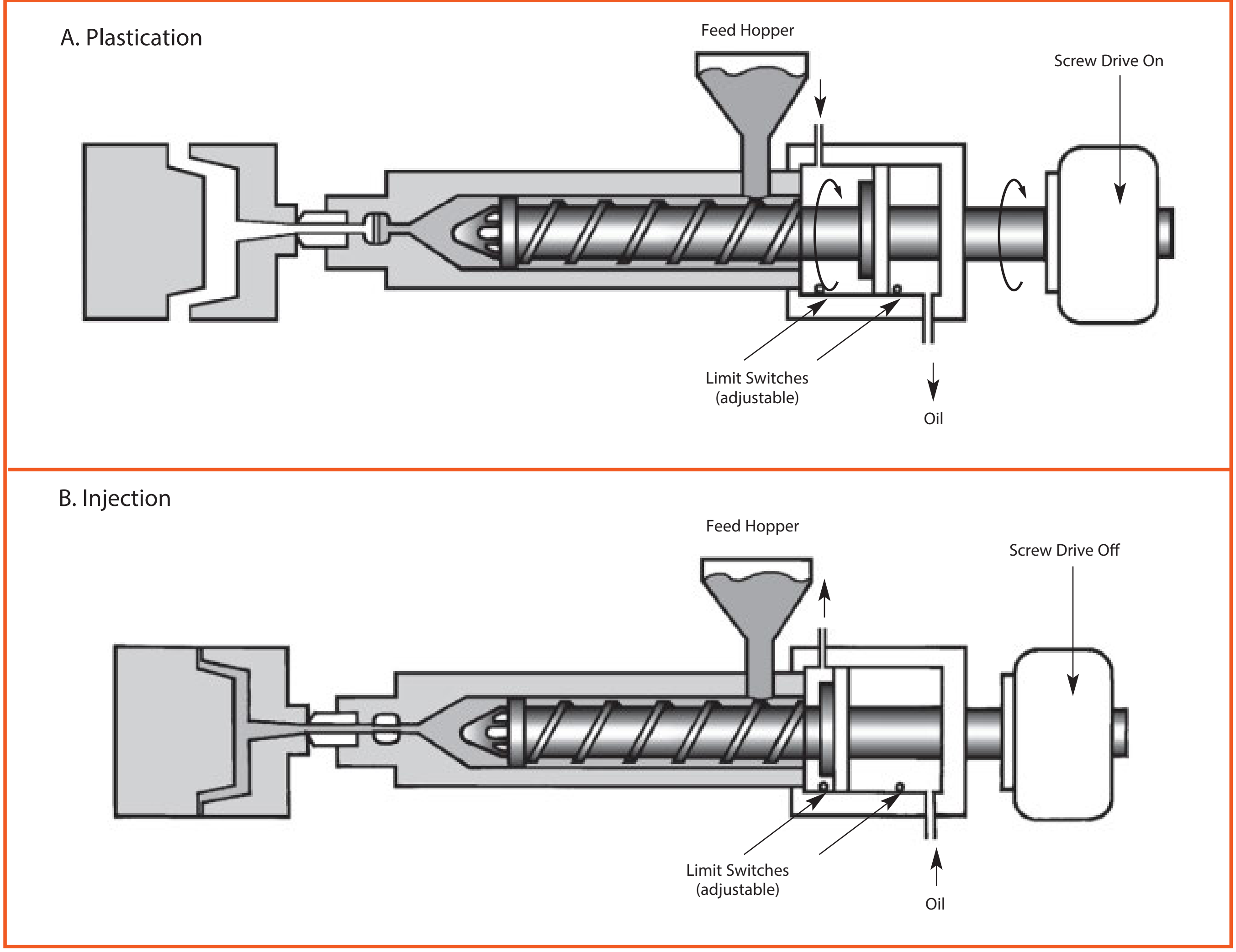
3.2 The Molding Process

With all thermoplastic polyester materials, careful process control is essential to produce consistent highquality parts. Part quality and performance depend as much on proper processing as on part design. Failure to maintain consistent processing conditions will lead to production of variable parts.

3.2.1 Plastication

In this first stage of processing, 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. See Figure 3.1 for a schematic diagram of the main elements of an injection molding machine.

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



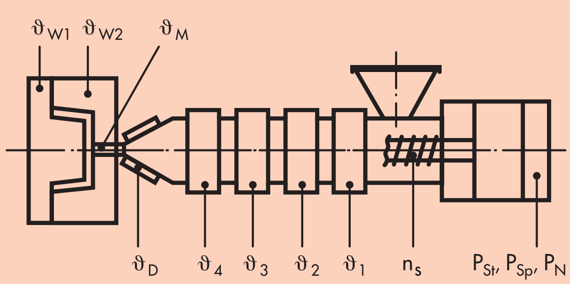
3.2.2 Injection

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 consists primarily of a barrel with a screw inside it and a drive motor. 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. 3.2 • Injection molding conditions



		Basic Grades	Reinforced Grades	Celanex 2302/ 2303 GV/xx
ϑ_1	=	240-250°C	250-260°C	250-260°C
ϑ_2	=	240-250°C	250-260°C	250-260°C
ϑ_3	=	245-255°C	255-265°C	260-270°C
ϑ_4	=	245-255°C	255-265°C	260-270°C
ϑ_D	=	250-260°C	260-270°C	265-275°C
ϑ_M	=	250-260°C	260-270°C	265-275°C
ϑ_{W1}, ϑ_{W2}	=	75-85°C	75-100°C	90-120°C

Maximum residence time in the cylinder: 5-10 min

P_{Sp} = 600-1000 bar P_N = 400-800 bar P_{St} = 10-30 bar

Injection rate: high

Nozzle design: preferably free-flow

Predrying

ϑ_{Dr} = 120-140°C, 2-4 h, res. humidity ≤0.02%

Predrying with dry-air drier

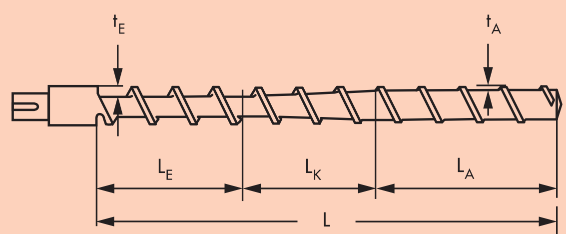
ϑ_1, ϑ_2-ϑ_D	°C	Cylinder temperatures, nozzle temperature
ϑ_M	°C	Melt temperature
ϑ_{W1}, ϑ_{W2}	°C	Tool temperature
n_S	min^{-1}	Screw speed
P_{St}	bar	Back pressure
P_{Sp}	bar	Injection pressure
P_N	bar	Holding pressure

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 meter the melt into the space in front of the screw, where it is held until the screw moves forward, forcing the molten resin through a nozzle into the die.

For processing materials with crystalline melting points and relatively low melt viscosities such as Celanese's polyester resins, the screw L/D ratio should be in the range of 16:1 to 24:1 with a metering zone of 3 or 4 flights. The feed zone should account for about half the screw length, with the remaining half equally divided between transition and metering zones. The screw compression ratio, i.e., the ratio of flight depth in the feed zone to that in the metering zone, should be in the range of 3:1 to 4:1.

Fig. 3.3 • 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 3.4 and 3.5.

3.3.4 Clamping Systems

The clamp keeps the mold closed by either a toggle mechanism or a hydraulic cylinder. Polyester resins can be processed on either type. The clamp force should be 3 to 4 tons per square inch of projected surface area. Runner area should be included in this calculation.

3.3.5 Mold Construction

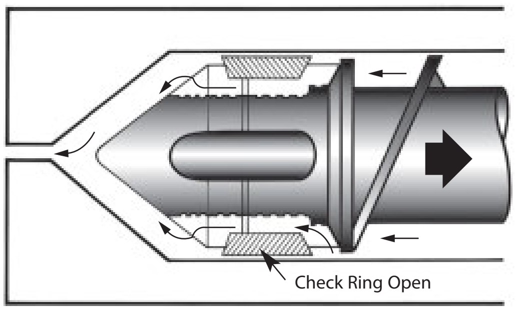
Molds should be made from tool steel. The recommended value for mold steel hardness for all Celanese's polyester resins is H13.

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, particularly with Impet® PET grades.

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

Plastication



Injection

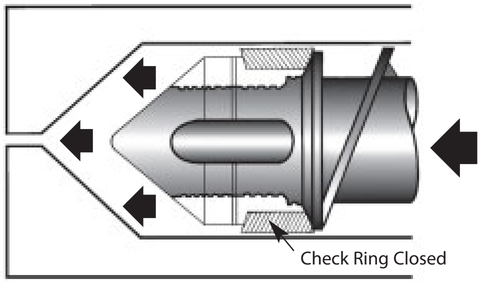
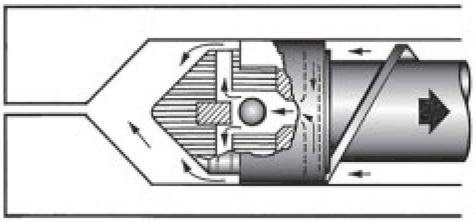
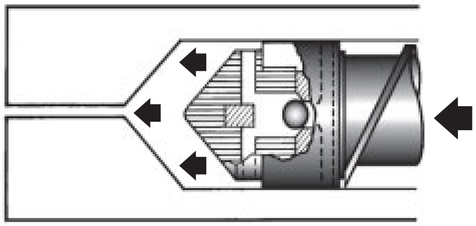


Fig. 3.5 • Internal Ball Check Nonreturn Valve Used on Reciprocating Screw Injection Molding Machines

Plastication



Injection



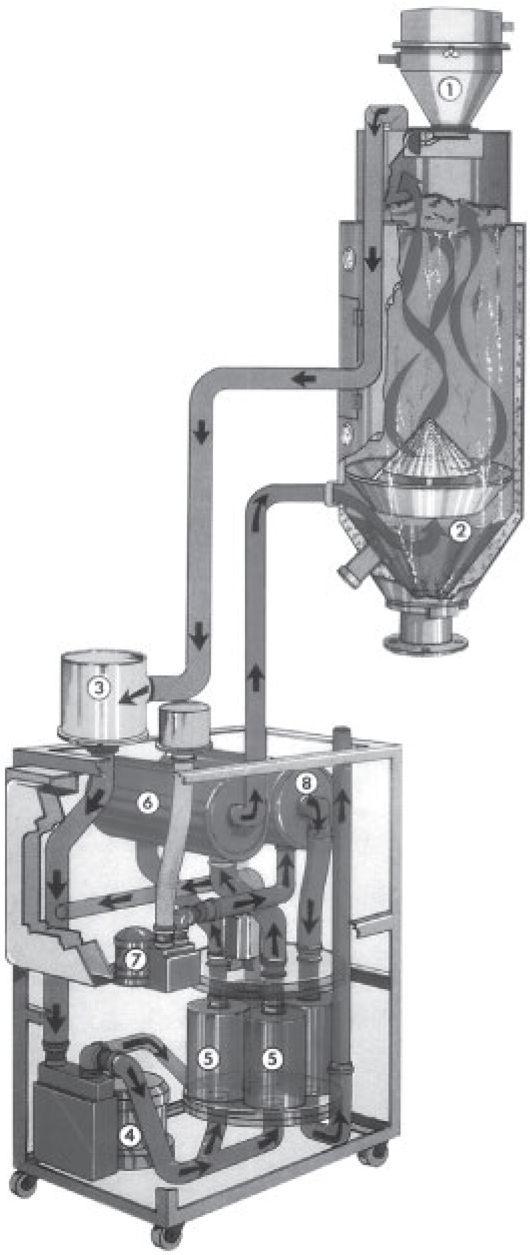
3.4.1 Drying Equipment

Polyester resins should be properly dried in a dehumidifying hopper drier, such as is shown in Figure 3.6. Drying in a hot air oven is not recommended because:

- A bed depth greater than about 1 to 1.5 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 being dried in the oven at the same time or by residue from a previous job

If there is no option but to use a hot air oven, trays should be thoroughly cleaned, as should their racking supports, and bed depth should be kept below 1 to 1.5 inches.

Fig. 3.6 • 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

Acceptable moisture levels for virgin or reground polyester resins are 0.02% for Vandar® PBT alloys and Celanex® PBT, and 0.01% for Impet® PET. To achieve these levels, drying times and temperatures should be as shown in Table 3.1. However, if the material is to be dried overnight, temperatures can be reduced to 93ºC (200°F). For best results, the recommended moisture levels must be achieved and maintained while processing the polyester resins.

Table 3.1 • Drying Guidelines for Polyester Resins

Resin Family	Time, hr.	Temperature, °C (°F)
Celanex PBT	4	121 (250)
Vandar PBT Alloys	3-4	107 (225)
Impet PET	4	135 (275)

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 material processing guidelines provide general molding recommendations, the molder should determine optimum conditions for each specific part and the mold and machine combination being used to make it.

3.6.1 Safety and Health

Before starting to mold parts from any of Celanese's polyester resins, obtain and review the appropriate Material Safety Data Sheet (MSDS) for that material. An MSDS for each available grade can be found on Celanese's web site, www.celanese.com, or obtained by calling Celanese Product Information Services at 1-800-833-4882.

3.6.2 Processing Conditions

The polyester product line offers an exceptionally diverse performance range. To obtain best results from an individual grade, the material should be processed at the conditions appropriate for that grade. To obtain processing recommendations for any product, please see the relevant data sheet on Celanese's web site (www.celanese.com), or call Celanese Product Information Services at 1-800-833-4882.

Table 3.2 • Typical Injection Molding Parameters for Polyester

	Polyester Product Family		
	Celanex PBT	Vandar PBT Alloys	Impet PET
Molding Parameter			
Mold Temperature °C (°F)	38-121 (100-250)	38-121 (100-250)	110-121 (230-250)
Melt Temp °C (°F)	238-260 (460-500)	238-282 (460-540)	271-299 (520-570)
Screw Speed, rpm	60-125	60-125	50-125
Back pressure, psi	0-50	0-100	0-25
Injection Speed	Fast	Medium – Fast	Medium – Fast
Cushion, in (mm)	0.125 (3)	0.125 (3)	0.125 (3)
Barrel Settings °C (°F)			
Feed Zone	232-249 (450-480)	232-254 (450-490)	260-271 (500-520)
Center Zone	238-254 (460-490)	238-260 (460-500)	271-277 (520-530)
Front Zone	243-260 (470-500)	243-266 (470-510)	277-282 (530-540)
Nozzle	249-260 (480-500)	249-271 (480-520)	277-288 (530-550)

Table 3.3 • Injection Molding Parameters for Celanex® PBT grades 3126, 3216 and 3316

Molding Parameter	Setting
Mold Temperature °C (°F)	66-93 (150-200)
Melt Temperature °C (°F)	238-249 (460-480)
Screw Speed, rpm	60-125
Back pressure, psi	0-25
Injection Speed	Fast
Injection Pressure	As needed to fill mold
Cushion, in (mm)	0.125 (3)
Barrel Settings	**°C (°F)**
Feed Zone	238-249 (460-480)
Center Zone	242-254 (4/0-490)
Front Zone	243-254 (470-490)
Nozzle	249-260 (480-500)

3.6.3 Mold Temperature

Mold temperatures are generally kept to the lower end of the range, typically 38-66°C (100-150°F) for unfilled materials. Unlike many other glass-reinforced resins, Celanex PBT can be molded to have a smooth glossy surface even in a relatively cool mold. Higher tool temperatures are used to obtain the ultimate in surface gloss and uniformity, to maximize crystallinity and to minimize molding and post-molding shrinkage. To obtain good crystallinity, higher mold temperatures should be employed with Impet® PET, especially when molding small parts.

3.6.4 Injection and Holding Pressure

Keep injection pressure low when starting the molding cycle in order to 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. Because of their ease of flow, Celanese's polyester resins require only moderate injection pressures, generally in the range of 50% to 70% of machine maximum.

3.6.5 Injection Speed

Celanex PBT resins are very fast cycling materials that set up quickly, so a high fill speed is generally desirable. Nevertheless, in some cases slowing down the injection speed may reduce warpage due to flow orientation of the glass fibers in the material.

3.6.6 Screw Speed and Cushion

For glass-reinforced grades, screw speed should be kept to the lower end of the range to minimize glass fiber breakage and possible reduction in properties.

3.6.7 Trouble Shooting

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 trouble-shooting recommendations in Table 3.4. Try them in the order in which they are listed under each problem category.

Table 3.4 • Trouble Shooting Guide – Injection Molding

Short Shots, Poor Surface Finish
Increase injection pressure
Decrease cushion
Raise cylinder temperature
Raise mold temperature
Increases 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 (unfilled grades only)
Increase back pressure (unfilled grades only)
Use lubricated resin
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

Table 3.4 • Trouble Shooting Guide – Injection Molding

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
■ Lowering 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
■ Lowering 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 for all polyesters)
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

Table 3.4 • Trouble Shooting Guide – Injection Molding

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 under cuts 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 by:
■ Raising cylinder temperature
■ 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

Table 3.4 • Trouble Shooting Guide – Injection Molding
Unmelted Pellets
Increase melt temperature
Increase back pressure
Dry/preheat the resin
Use a press with proper screw design (see "Screw Design" above for guidelines)
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

Table 3.4 • Trouble Shooting Guide – Injection Molding
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 melting 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 trouble shooting guide following below, contact your local Celanese representative or call Celanese Product Information Services at 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, www.celanese.com, or by calling Celanese Product Information Services at 1-800-833-4882. Use process controls, work practices and protective measures described in the MSDS to control workplace exposure to dust, volatiles or vapors.

3.7.2 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.

3.7.3 Extruder Barrel

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

3.7.4 Screw Design

Screw designs for polyester extrusion 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. 3.7, the feed zone screw channel should be approximately 0.4 inch deep, while the metering zone screw channel should gradually reduce to approximately 0.1 inch, with the overall length-to-diameter ratio being 30: 1 or greater. Feed zone length should comprise one-third of the total screw length. A long and gradual transition section of a further third of the screw length 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).

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. A typical "polyethylene type" screw design meets the requirements for extrusion processing of polyesters, as do screws designed for nylon 6,6, provided that the transition zone is of sufficient length.

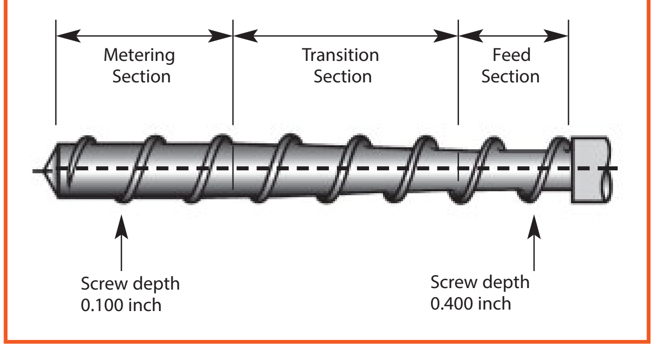
3.7.5 Breaker Plate and Screens

Screens (usually 80-100 mesh) are recommended for unfilled polyesters. 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.

3.7.6 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.

Fig. 3.7 • Typical Screw Design



3

3.7.7 Processing Conditions

Tables 3.5, 3.6 and 3.7 respectively show recommended processing conditions for extrusion of various Celanex® PBT, Vandar® PBT alloy and Impet® PET resins. For recommendations for grades other than those listed, please contact Celanese Product Information Services at 1-800-833-4882.

Table 3.5 • Typical Extrusion Temperature Ranges for Celanex PBT

Parameter	Grade 2002, 2401MT, 2016	Grade 1600A, 1700A, 2001
Barrel Zone 1, °C (°F)	232-249 (450-480)	243-271 (470-520)
Barrel Zone 2, °C (°F)	232-249 (450-480)	249-271 (480-520)
Barrel Zone 3, °C (°F)	232-249 (450-480)	249-271 (480-520)
Barrel Zone 4, °C (°F)	238-254 (460-490)	249-271 (480-520)
Barrel Zone 5, °C (°F)	238-254 (460-490)	249-271 (480-520)
Adapter, °C (°F)	238-254 (460-490)	249-271 (480-520)
Die, °C (°F)	238-260 (460-500)	249-271 (480-520)
Melt, °C (°F)	238-260 (460-500)	243-271 (470-520)

Table 3.6 • Typical Extrusion Temperature Ranges for Vandar PBT Alloys

Parameter	Grade 2100, 2500, 4602Z	Grade 6000
Barrel Zone 1, °C (°F)	232-249 (450-480)	243-260 (470-500)
Barrel Zone 2, °C (°F)	232-249 (450-480)	243-260 (470-500)
Barrel Zone 3, °C (°F)	232-249 (450-480)	249-271 (480-520)
Barrel Zone 4, °C (°F)	238-254 (460-490)	254-277 (460-530)
Barrel Zone 5, °C (°F)	238-254 (460-490)	254-277 (460-530)
Adapter, °C (°F)	238-254 (460-490)	254-277 (460-530)
Die, °C (°F)	238-260 (460-500)	260-282 (500-540)
Melt, °C (°F)	238-260 (460-500)	260-282 (500-540)

Table 3.7 • Typical Extrusion Temperature Ranges for Impet PBT

Parameter	Grade 330R
Barrel Zone 1, °C (°F)	254-271 (490-520)
Barrel Zone 2, °C (°F)	254-271 (490-520)
Barrel Zone 3, °C (°F)	260-282 (500-540)
Barrel Zone 4, °C (°F)	266-288 (510-550)
Barrel Zone 5, °C (°F)	266-288 (510-550)
Adapter, °C (°F)	266-288 (510-550)
Die, °C (°F)	271-293 (520-560)
Melt, °C (°F)	271-293 (520-560)

3.7.8 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. This balance will shift as shear heating increases with greater extruder size. Changes in viscosity and output rate of the melt cause pressure changes. Diaphragm type pressure transducers are commonly used to monitor such fluctuations in pressure.

3.7.9 Startup

When starting up an empty machine, set the temperature controllers for the die, adapter and barrel using the appropriate temperatures shown in Table 3.3. When these reach their operating temperatures, bring the remaining barrel temperatures up to the proper settings. After temperatures have been stable for 20 to 30 minutes, begin screw rotation at low RPM and start feeding resin into the hopper. Carefully check both the ammeter and pressure gauges. As melt appears at the die, it may be hazy initially as air is cleared from the system. Die temperature and head pressure should start to stabilize as melt flow smooths out.

3.7.10 Purging and Shutdown

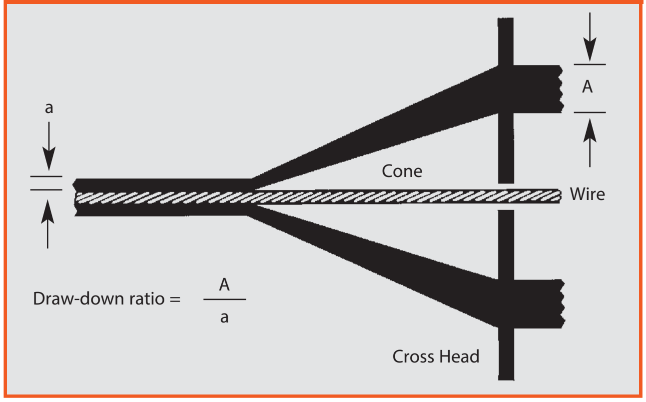
A machine should never be shut down while polyester remains in it. As recommended in section 3.1.4, medium-to-high density polyethylene should be used to purge the extruder. Temperature controllers should remain set at running conditions. Purge all of the polyester from the extruder. Continue running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

3.7.11 Wire Coating

In wire coating, an extruded tube of polyester 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 3.8, the drawdown 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 polyester polymers should be between 6:1 and 10:1.

Fig. 3.8 • Polyester in Wire Coating



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 polymer coats the wire) is very important. It is generally between 1.5 and 2 inches (37 and 50 cm), and is best defined precisely 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.

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. Air cooling and cone length should be balanced to obtain the best adhesion to the wire and ensure integrity of the coating. Water temperature in the cooling trough is critical. If the water is too cold (below about 16°C (60°F) for Celanex® PBT and most Vandar® PBT alloy grades), the coating can be frozen into an amorphous state. The amorphous material can later crystallize, possibly causing the 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 post-crystallization and eliminates or minimizes spoolset, giving better mechanical properties to the wire.

3

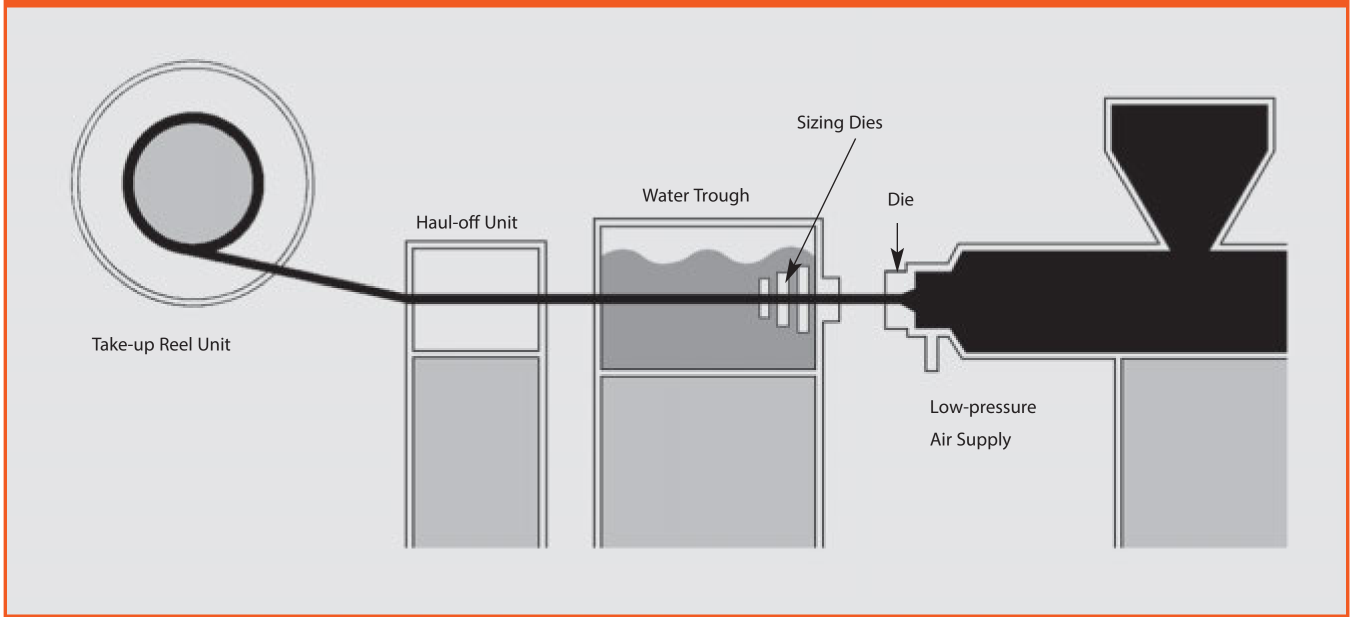
3.7.12 Tube Extrusion

Polyester resins can be readily extruded into tubing up to 3/8" (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 Tables 3.5 through 3.7 as starting points. Dies like those used in wire coating are employed in free extrusion of tubing, with a general set-up as shown in Figure 3.9. Inside the water trough, the extruded tube of resin is pulled through one or more sizing rings to control the outer diameter.

Vacuum Tank

For tubing of diameter greater than 0.5" (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 the semi-crystalline nature of polyester polymers gives them a relatively narrow range between melting and freezing.

Fig. 3.9 • Polyester in Tube Extrusion



3.7.13 Sheet Extrusion

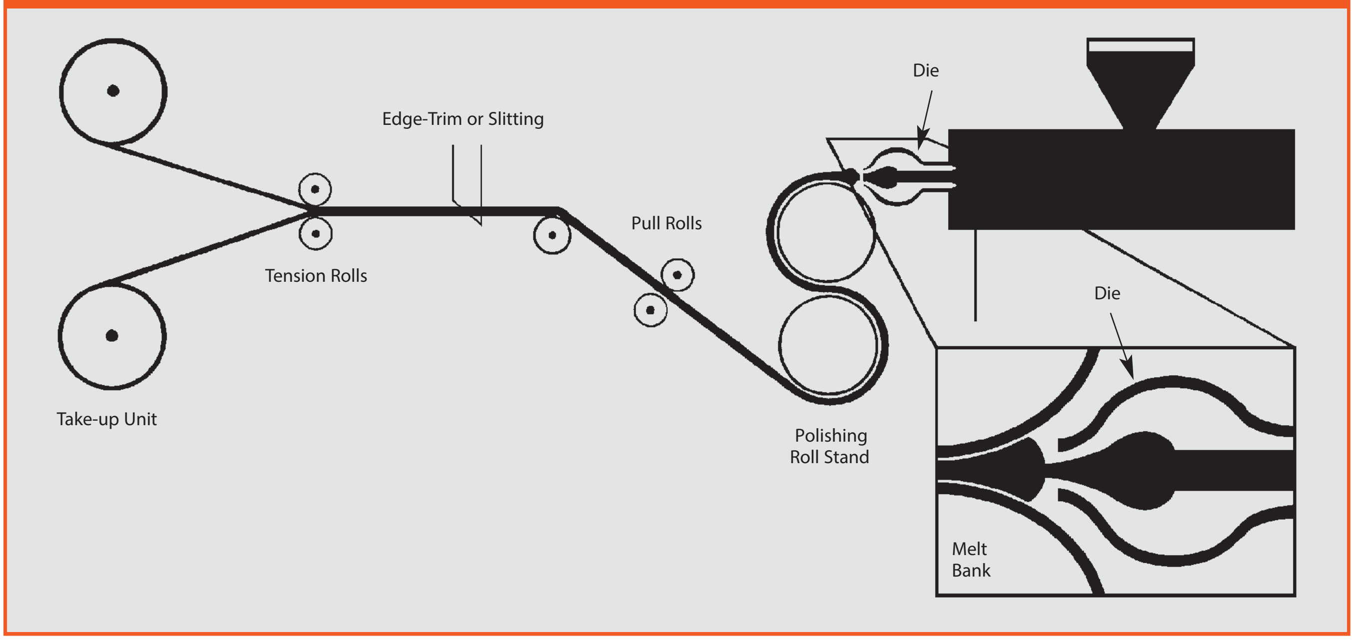
As shown in Figure 3.10, polyester sheet may be extruded with standard equipment, typically including an extruder, sheet die, polishing rolls, pull rolls, edge trim knives and winder. A flex lip coat-hanger die is best suited for sheet extrusion, as it does not have the stagnant areas found in "T" dies. As with other melt processing equipment for polyesters, 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 temperature control across the die face is also necessary.

The air gap should be as small as possible and the melt bank (between the nip rolls) should also be as small as possible. Too large a melt bank causes stress in the sheeting while too small a bank results in non-uniform sheet thickness.

Polishing Rolls

These rolls are used to improve the surface finish of the sheet. Normal temperature settings for a three-roll stack are 38-77°C (100-170°F) for the top roll, 38-71°C (100-160°F) for the middle roll and 36-71°C (100- 160°F) for the bottom roll. Bear in mind that internal cleanliness is a key factor in roll heat transfer.

Fig. 3.10 • Polyester Sheet Extrusion



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3.7.14 Extrusion Trouble Shooting

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 generalized recommendations in Table 3.8. Try them in the order in which they are listed under each problem type, having regard for both the specific process and the material being processed. For example, glass-reinforced Impet® PET grades are not used in wire coating, so cone length and other wire coating recommendations would be inapplicable to them.

3.7.15 Monofilament

Unfilled Celanex® PBT resins can be used to prepare monofilaments with a range of properties. The final monofilament properties depend greatly on drawing equipment and conditions. While initial extruder conditions should be as recommended in Table 3.5, subsequent adjustments should be made to optimize drawing and other monofilament processing steps to suit the equipment and process of the monofilament manufacturer.

Table 3.8 • Trouble Shooting Guide – Extrusion

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	■ Use correct screw ■ For Vandar® PBT alloys, increase back pressure ■ Check controllers for proper functioning
	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

Table 3.8 • Trouble Shooting Guide – Extrusion

Problem	Typical Cause	Corrective Action
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
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 – Non-uniform extrusion rate and head pressure	■ Lower rear barrel temperature ■ Cool hopper throat
	Moisture in feed	■ Dry material to proper level before use

Table 3.8 • Troubleshooting Guide – Extrusion

Problem	Typical Cause	Corrective Action
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
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

Table 3.8 • Troubleshooting Guide – Extrusion

Problem	Typical Cause	Corrective Action
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
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

3.7.16 Meltblown Media

High-performance meltblown media can be prepared from Celanex® PBT polymers. Such media are more thermally stable and exhibit significantly lower shrinkage than those made from PET. By selecting the appropriate grade of Celanex PBT and adjusting process conditions, a processor can obtain a wide range of fiber diameters. Initial extruder conditions as recommended in Table 3.5 may be used to start the process.

To achieve best web integrity and minimize fly generation, subsequent adjustments should be made to optimize extrusion, blowing and other processing steps to suit the equipment and process of the manufacturer. Celanese offers special grades of Celanex PBT with less fly generation. For further information on these grades and specific recommended process conditions for meltblowing applications, please call Celanese Product Information Services at 1-800-833-4882.

3.7.17 Spunbond Webs

Celanex PBT polymer and copolymer grades can be used for making monocomponent and bicomponent spunbond webs with a desirable range of properties. The final web properties depend greatly on the

spinning, take-off and laydown conditions of the spunbond machine. As with all extrusion-based processes, initial extruder conditions should be as recommended in Table 3.5, with subsequent adjustment optimized to suit the spinning and other spunbond process steps. For further information and specific recommended process conditions for spunbond applications, please call Celanese Product Information Services at 1-800-833-4882.

Golf players may practice with Sam Snead's "PERFECT LIE Practice Tee" made with Vandar® PBT.

4. Part and Mold Design

4.1 Introduction

There is a complex interplay between material selection, part design and mold design. The right choice of material is driven by a focus on those intrinsic properties that are needed for satisfactory performance of the final part as a system component. As polyester resins are stiff semi-crystalline materials, care needs to be taken with such areas as corner radii and undercut tolerances. While the greater flexibility of Vandar® PBT alloys may allow somewhat less stringent requirements, typical plastics design principles for rigid plastics should still be followed with these resins.

A first step in any design is to establish performance criteria for the final part and whatever system of which it may be a component. Factors to be considered include, for example:

- Functional requirements of part and system
- Ability to simplify design or eliminate parts by using moldable plastics
- 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 of these factors can be expanded in such detail as best fits the application and a design then drawn. It is always preferable to go from the first design to making a prototype part by machining or prototype molding in an inexpensive mold cut from aluminum or a suitable alloy. Molding is preferable to machining in that it not only avoids machining marks, but also enables gate location to be investigated. Parts from this step can then be tested in situations as close to the intended use as possible and specifications developed from the results.

4.1.1 Material Selection

Once it is determined that part performance requirements will be met by a polyester resin or alloy, a specific grade can be selected. The broad property range available from Celanese polyester product line enables the best balance of properties for the application to be readily achieved.

4.1.2 Wall Thickness

Wall thickness, particularly in semi-crystalline resins, should be kept to the minimum required for satisfactory 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. While thick-walled parts up to 0.5 in (12.7 mm) can of course be molded from polyesters with appropriate sprue, runner and gate design, such sections should be cored to reduce the effective thickness as much as possible to be consistent with retaining adequate properties. For small and medium-sized parts, a practical wall thickness can be as low as 0.03 in (0.7 mm), but for larger parts, wall thicknesses of 0.06 in (1.5 mm) or greater are 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 in different 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 well designed and properly 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 in (19 mm). Where sink marks are not a concern, rib thickness may be 75% to 100% of the adjacent wall thickness, and they may be located in areas where 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 or to provide mounting or fastening points. Guidelines to be considered when designing a boss or stud include the following:

- The height should not b e 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 autobody components, the length of the mounting boss(es) should not provide more than .125 in (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 three-quarters of the length of the boss.

4.1.5 Fillets and Radii

Sharp corners should always be avoided in molded plastic parts, even in the more ductile Vandar® PBT alloy materials. 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 there may be variability in either the material or 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 without sacrificing product performance, part designers should determine whether very tight tolerances are really necessary and if they can be economically justified. In particular, since temperature-driven dimensional changes can be many times greater than specified tolerances, it may be unreasonable to specify close tolerances on a part that will be exposed to a wide

temperature range. In general, dimensional tolerances that can routinely be held with Celanex® PBT and Impet® PET thermoplastic polyester resins are:

- ± 0.002 in/in (mm/mm) on the first inch (25 mm)
- ± 0.001 in/in (mm/mm) on each subsequent inch (25 mm)

Similar dimensional tolerances may be held with certain Vandar® PBT alloy resins. However, because different Vandar PBT alloy grades may have substantially different compositions, please consult Celanese Product Information Services at 1-800-833-4882 for gradespecific tolerance recommendations.

4.1.7 Threads

Standard thread systems such as Unified or Acme can be used in designing threads for Celanese's polyester resins. Because plastics have lower shear strength than metals, less torque is required to strip a plastic thread in any given design. On the other hand, most metal threads are greatly over-designed and the exceptionally high stripping torques thus obtained will far exceed actual performance requirements. Accordingly, with proper thread design, polyester resin components can be designed with high stripping torques which are high enough for many demanding applications.

Internal or external threads can be molded in all polyester resins, but it may be difficult to machine threads in softer Vandar PBT alloy grades because of material "squirm." Threads may be machined with standard metalworking tools in Celanex® PBT, Impet® PET and higher modulus grades of Vandar PBT alloy. This approach is generally recommended for threads below 6.4 mm (0.25 in) in diameter. To prevent chipping during tapping, cored holes for post-molding machine-tapping should be provided with a chamfer starting from a shallow counterbore as shown in Figure 4.1. Larger internal threads may be formed by a threaded core pin that is unscrewed either manually or automatically. External threads can be formed in the mold by splitting the thread along its axis or by unscrewing the part from the mold. The latter method must be used in cases where a parting line or mold flashing are unacceptable.

Standard thread systems can be used, but coarse threads are preferable to fine. Threads finer than 28 pitch or closer than Class 2 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 in (0.1-0.3 mm) is recommended. The bearing area for the screw head should be chamfered to match the screw profile.

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. As 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.

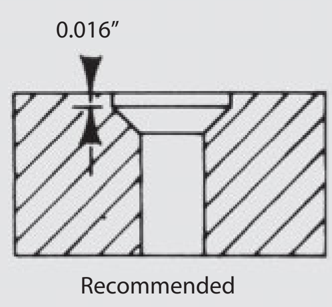
4.1.9 Draft

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. Although parts with zero draft have been successfully molded, a draft angle of at least .5° per side is recommended for Celanex PBT, Impet PET and higher modulus grades of Vandar PBT alloy, and a draft of 1° is suggested for best results. For the softer grades of Vandar PBT alloy, a draft angle of as much as 2° per side may be needed.

4.1.10 Surface Finish

Because Celanese's polyester resins flow well and possess a substantial degree of crystallinity, they can provide excellent replication of surface features, enabling a wide variety of surface finishes to be achieved. The corollary to this is that if a high gloss is required, mold surfaces must be highly polished.

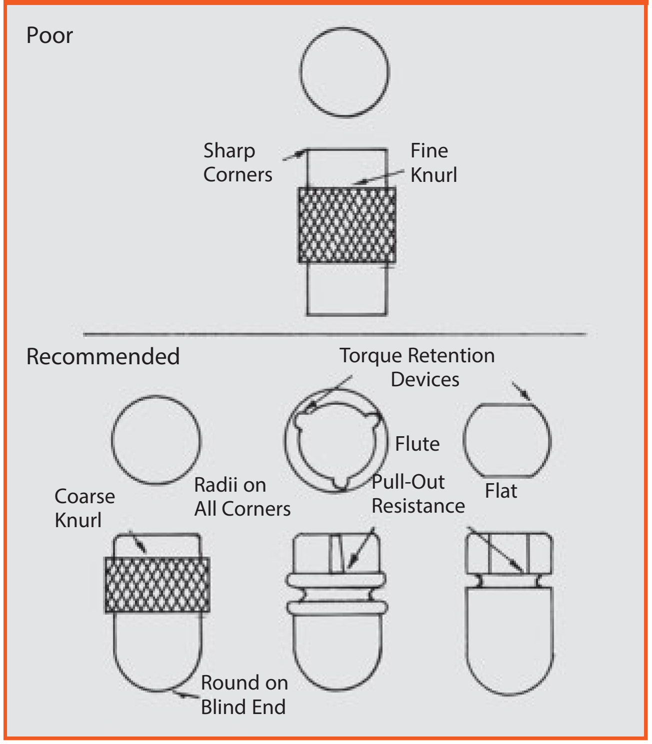
Fig. 4.1 • Chamfered Hole for Machine Tapping



4.1.11 Molded-in Inserts

Thanks to the general high strength and good creep resistance of the polyester resins, molded-in inserts are well retained, even when tested under thermal and moisture cycling. Subject to lower pull-out limits, such inserts may also be used with softer Vandar® PBT alloy grades. The corners of 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. These recommendations are illustrated in Figure 4.2.

Fig. 4.2 • Poor and Recommended Designs for Molded-In Inserts



4.2 Mold Design

Celanese's polyester resins 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 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 polyester 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 the 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 the polyesters, a wide variety of cavity surface finishes may be effectively employed. Of course, as the part surface cannot be glossier than the tool surface, the mold surface must be highly polished in order to achieve a high gloss finish on the part.

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 nonuniform by creating visual "hot spots." If this 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 the polyester resins. To facilitate ejection of the sprue, its 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

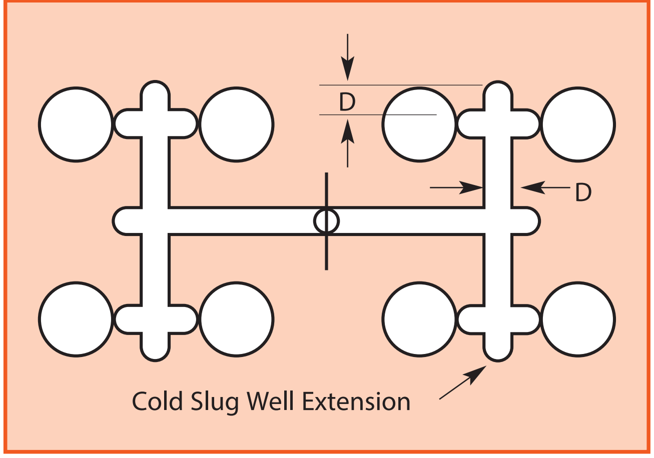
For most efficient flow with least frictional drag, full round runners are strongly recommended for molding of all polyester materials. If this cannot be done, trapezoidal runners are the second best choice. Generous radii should be provided in the runner system where the sprue joins the runner. Suggested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

Table 4.1 • Suggested Runner Dimensions

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

On multiple-cavity molds with primary and secondary runners, the primary runner should extend beyond its intersection with the secondary runner. As shown in Figure 4.3, this provides a cold slug well for the runner flow front. The extended length should be at least equal to the runner diameter.

Fig. 4.3 • Balanced Runner and Cavity Layout



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. Although polyester resins are readily moldable in family (heterocavity) molds, they are in general not recommended for production of close tolerance parts.

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 so that only molded parts are removed from the machine each time the mold opens.

Continued cost increases have driven the growth of automated runnerless molding. This technology is widely available and polyester compounds have been successfully molded in many types of commercially available runnerless molds. Good molding practice in these systems calls for reliable temperature control of the runner system, which should be constructed to 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 Celanese's polyester resins depends more on the part than the resin. Various gate types are shown in Figures 4.4 and 4.5. The location of a gate should be chosen to achieve a flow pattern that will minimize anisotropic shrinkage that could possibly cause distortion and warpage in the part. Anisotropy may also be caused by flow orientation of reinforcing fibers. 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.

Sharp flow discontinuities may lead to breakage and length reduction of reinforcing fibers. To minimize such effects, it is desirable to gate the part into a thick-walled section and to incorporate radii where the runner joins the gate as shown in Figure 4.6. A general rule of thumb calls for gate width to be as wide as the part is thick and two-thirds as deep. Tables 4.2 and 4.3 provide gate size recommendations keyed to part thickness.

Table 4.3 • Suggested Gate Dimensions, Direct Gate, 3-Plate Mold Secondary Sprue

Part Thickness, mm (in)	Gate Depth, mm (in)	Land Length, mm (in)
<3.2 (0.125)	0.8-1.3 (0.030-0.050)	1.0 (0.040)
3.2-6.4 (0.125-0.250)	1.0-3.1 (0.040-0.120)	1.0 (0.040)

Table 4.2 • Suggested Gate Dimensions, Rectangular Edge Gate

Part Thickness, mm (in)	Gate Depth, mm (in)	Gate Width, mm (in)	Land Length, mm (in)
< 0.8 (0.030)	#0.5 (0.020)	#1.0 (0.040)	1.0 (0.040)
0.8-2.3 (0.030-0.090)	0.5-1.5 (0.020-0.060)	1.0-2.3 (0.040-0.090)	1.0 (0.040)
2.3-3.2 (0.090-0.125)	1.5-2.2 (0.060-0.085)	2.3-3.3 (0.090-0.130)	1.0 (0.040)
3.2-6.4 (0.125-0.250)	2.2-4.2 (0.085-0.165)	3.3-6.4 (0.130-0.250)	1.0 (0.040)

Table 4.4 • Various Gate Types Used in Injection Molds

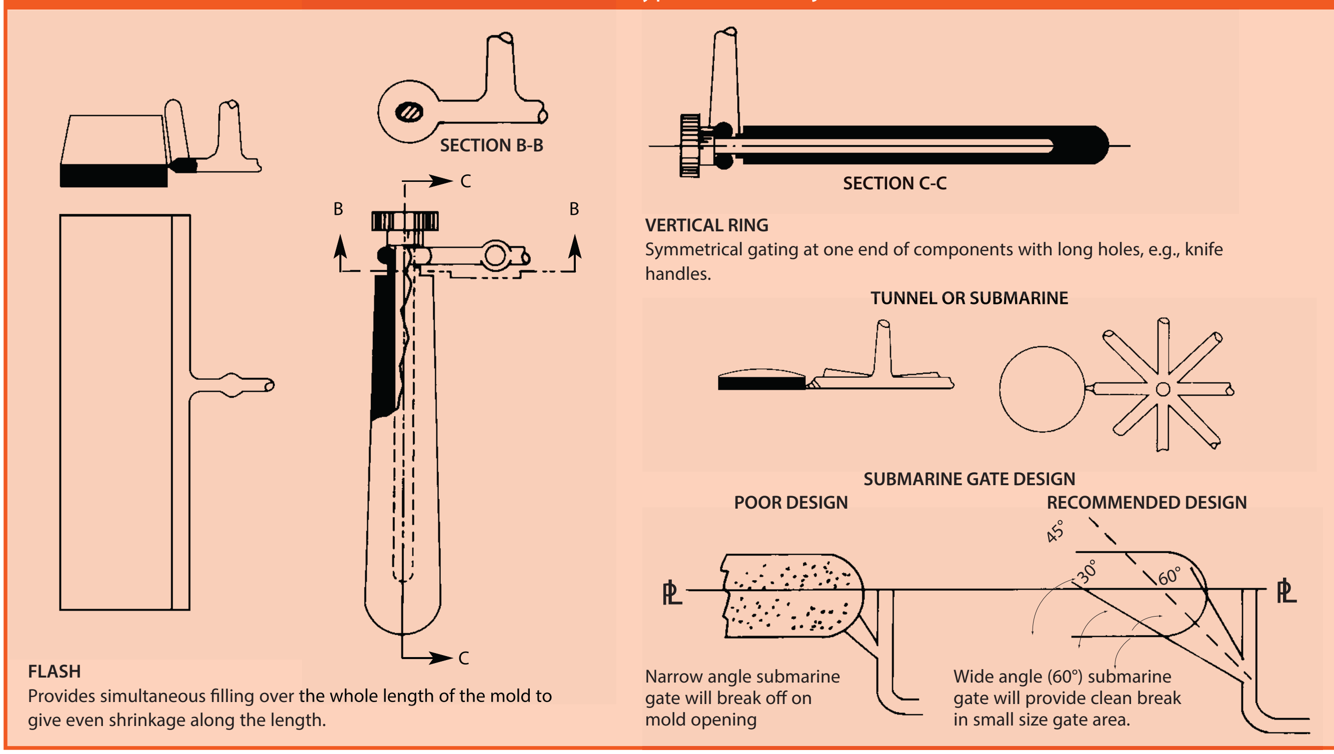
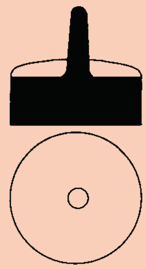
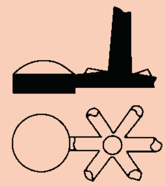


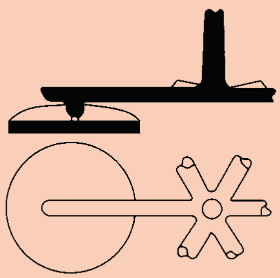
Fig. 4.5 • Various Gate Types Used in Injection Molds



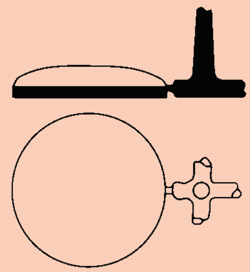
SPRUE: A simple design for single cavity molds and symmetry on circular shapes. Suitable for thick sections.



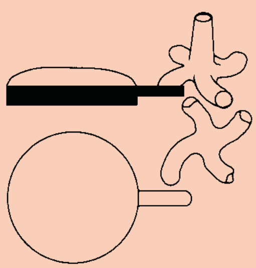
SIDE or EDGE: A simple design for multicavity molds. Suitable for medium and thick sections.



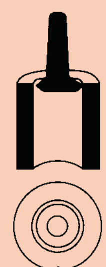
PIN (3 plate tool): Used to minimize finishing where edge gating is undesirable and for automatic degating. Only suitable for thin sections.



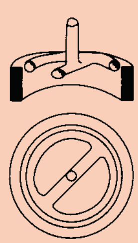
RESTRICTED or PIN: Provides simple degating and finishing. Only suitable for thin sections.



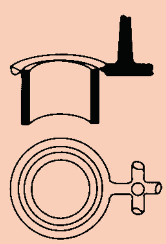
TAB: Used to stop jetting when other means are not available and when a restricted gate is desired. Also enables area of greatest strain to be removed from the molding.



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.

4.2.7 Venting

The high injection speeds achievable with polyester resins enable rapid mold filling. In such circumstances, 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 0.025 mm (0.001 in) deep by 3.2 mm (0.125 in) 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 3.2 mm (0.125 in) from the cavity. Proper venting is particularly critical at knit lines and in that portion of the cavity that is last to fill.

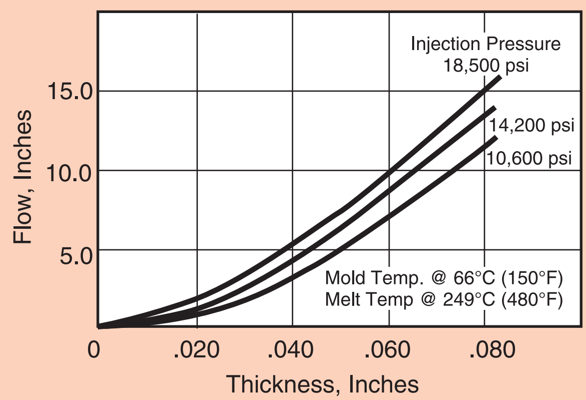
4.2.8 Mold Cooling

Inadequate or ill-designed mold cooling can significantly affect machine productivity and part quality. The semi-crystalline nature of Celanese's polyester resins enables them to solidify quickly from the melt, permitting achievement of fast cycle times. Removal of the heat of crystallization 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. Sufficient range for most polyester molding applications will be provided by temperature controllers capable of reaching 121°C (250ºF).

4.2.9 Melt Flow

Low melt viscosity and rapid crystallization are among the desirable properties of Celanese's polyester resins, providing quick mold filling and fast molding cycles. However, rapid crystallization does impose limits on how far the melt can flow when filling a mold. Melt temperature, mold temperature and injection pressure are the main process variables affecting melt flow length. Wall thickness also influences resin flow, with thicker sections affording greater flow lengths than thinner sections. Figure 4.6 shows the effect of wall thickness on flow length for Celanex® PBT grade 3300, a 30% glass reinforced resin.

Fig. 4.6 • Flow Versus Wall Thickness for Celanex 3300



4.2.10 Mold Shrinkage

Shrinkage values measured on standard ASTM or ISO test bars should only be used for material comparison and not for tool design. For accurate mold design, it is strongly recommended that shrinkage values be determined on actual parts made in prototype tooling before making the final tool. Measurements on the material to be used should be made on parts having the same geometry as the designed part. A range of molding conditions should be tested to establish how shrinkage may change with molding variables as well as tooling variations such as mold cooling and gating and weld line locations. Consult Celanese Product Information Services at 1-800-833-4882 for further information on part shrinkage before final mold sizing.

5. Post-Processing

5.1 Assembly

Components molded from Celanese's polyester resins are easily assembled using conventional plastic joining techniques. In selecting the method for joining components, consideration must be given to:

- Designing the parts so as to avoid or minimize surface damage to mating components during assembly process. Such damage could reduce key mechanical properties.
- The effect of 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 Vandar® PBT alloy grades. Certain kinds of joint designs may not be feasible with softer resins. 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. Circular barbed leg snap-fit elements are 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.

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. Where Emax is the maximum allowable elongation of the material, the maximum permissible interference depth, Hmax, is given by:

$$H_{max} = D_G \times E_{max}/100$$

Regardless of the type of snap-fit, there is a linear relationship between undercut depth and hub elongation, i.e., 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

Fig. 5.1 • Barbed Leg Snap-fit

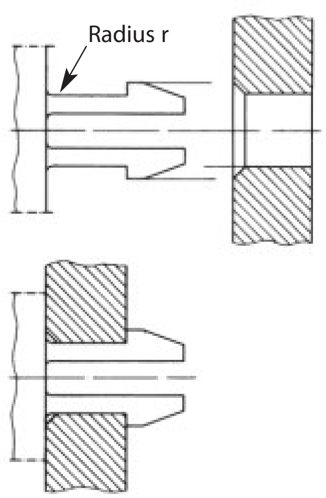
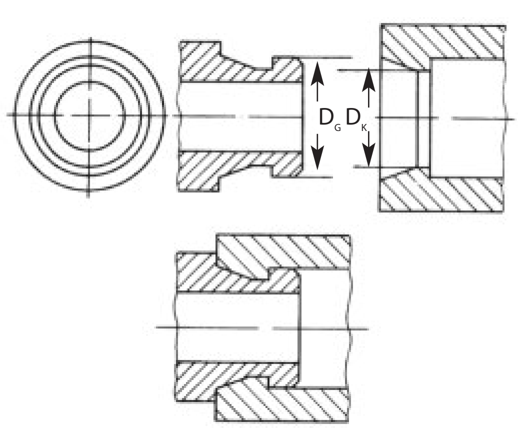


Fig. 5.2 • Cylindrical Snap-fit



functional requirements of the joint by adjusting the undercut depth and the assembly retaining angle.

5.1.2 Strain Limits in Snap-fit Applications

Because a snap-fit join tends to load parts in flexure, it is most appropriate to use flexural strain data in design calculations. However, tensile data may also be used if that is all there is available. Snap-fit design recommendations for the various polyester materials take account of the failure mode of the resin, i.e., whether it is by yield or break. Unfilled and unreinforced grades of Celanex® PBT and Vandar® PBT alloy typically show yield points. The following recommendations apply to such grades.

- 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.
- For materials with a clear tensile yield, the maximum allowable strain should be 70% of the yield strain for single snap applications and 40% of the yield strain for repeated snap use.

The filled and/or reinforced polyester resins typically have low elongation and generally break without showing a clear yield point. For such materials, 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.

5.1.3 Snap-on/Snap-in Fits

As shown in see 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.

5.1.4 Self-Tapping Screws

Both thread-cutting and thread-forming screws may be used to join parts made from Celanese's polyester resins. 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, pilot hole diameter should in general be slightly less than screw diameter. As threads may not cut or form adequately in softer Vandar PBT alloy grades, pull-out forces may be low and other methods of joining should be considered. Extensive driving and stripping torque measurements have been made on Celanex PBT 3300. These data are presented in Table 5.1 which also includes pull-out strength values.

Fig. 5.3 • Ball and Socket Snap-fit

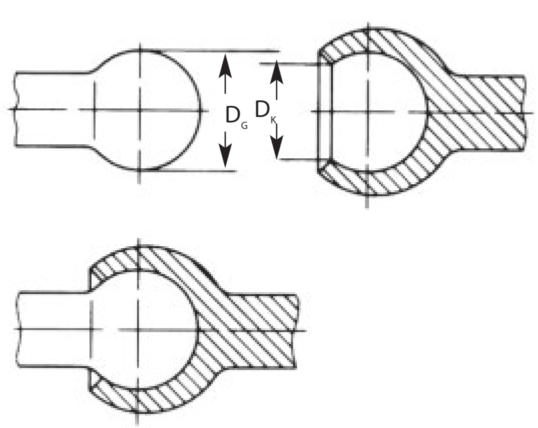


Fig. 5.4 • Snap-on/Snap-in Fits

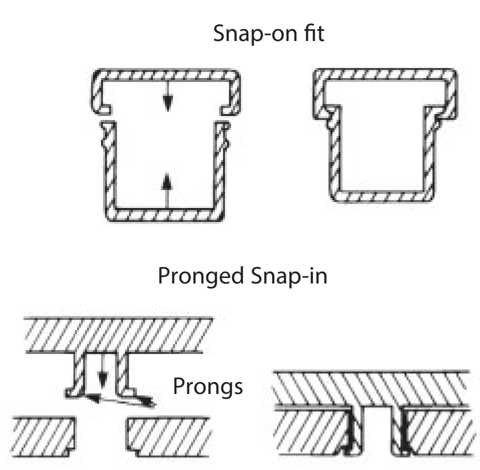


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Table 5.1 • Driving and Stripping Torques and Pull-Out Strengths of Self-Tapping Screws for Celanex® 3300

Screw Size	Penetration Depth mm (in.)	Pilot Hole Diameter mm (in.)	Drive Torque in-lb	Stripping Torque in-lb	Strip/Drive Ratio	Strip/Drive Differential in-lb	Pull Out Strength kg (lb)
Thread Forming							
2-28	4.8 (.188)	1.9 (.073)	1	5	5:1	4	—
	6.4 (.250)	1.9 (.073)	2	7	3.5:1	5	—
4-20	4.8 (.188)	2.5 (.098)	2	10	5:1	8	—
	6.4 (.250)	2.5 (.098)	3	13	4.2:1	10	—
6-19	6.4 (.250)	2.9 (.116)	4	22	5.5:1	18	159 (350)
	11.1 (.438)	2.9 (.116)	7	48	7:1	41	386 (850)
8-16	8.0 (.313)	3.8 (.149)	9	40	4.14:1	31	295 (650)
	12.7 (.500)	3.8 (.149)	12	75	6.2:1	63	590 (1300)
10-14	8.0 (.313)	4.4 (.173)	11	55	5:1	44	340 (750)
	12.7 (.500)	4.4 (.173)	17	100	6:1	83	658 (1450)
Thread Cutting (Shank Slotted)							
8-18	8.0 (.313)	3.3 (.130)	4	20	5:1	16	154 (340)
	12.7 (.500)	3.3 (.130)	6	36	6:1	30	—
9/32-16	12.7 (.500)	5.8 (.230)	11	54	5:1	43	318 (700)
	12.7 (.500)	5.8 (.230)	15	105	7:1	90	567 (1250)
Thread Forming (Blunt Point)							
8-18	8.0 (.313)	3.3 (.130)	7	28	4:1	21	195 (430)
	12.7 (.500)	3.3 (.130)	10	45	4.5:1	35	—
9/32-16	8.0 (.313)	5.8 (.230)	25	80	3:1	55	422 (930)
	12.7 (.500)	5.8 (.230)	30	132	4.4:1	102	771 (1700)
Thread Cutting							
4-24	8.0 (.313)	2.4 (.093)	4	11	3:1	7	195 (430)
	12.7 (.500)	2.4 (.093)	4	15	4:1	11	231 (510)
6-20	9.5 (.375)	3.1 (.120)	4	16	4:1	12	240 (530)
	12.7 (.500)	3.1 (.120)	4	28	7:1	24	286 (630)
8-18	9.5 (.375)	3.7 (.144)	5	26	5:1	21	304 (670)
	12.7 (.500)	3.7 (.144)	6	35	6:1	29	381 (840)
10-16	9.5 (.375)	4.3 (.169)	6	30	5:1	24	363 (800)
	12.7 (.500)	4.3 (.169)	9	43	5:1	35	454 (1000)
Thread Forming							
4-24	8.0 (.313)	2.4 (.093)	2.5	9	3.5:1	6	159 (350)
	12.7 (.500)	2.4 (.093)	2.5	16	6:1	13	177 (390)
6-20	9.5 (.375)	3.1 (.120)	3	18	6:1	15	268 (590)
	12.7 (.500)	3.1 (.120)	4	24	6:1	20	272 (600)
8-18	9.5 (.375)	3.7 (.144)	5	22	4.5:1	17	349 (770)
	12.7 (.500)	3.7 (.144)	8	28	3.5:1	20	358 (790)
10-16	9.5 (.375)	4.3 (.169)	6	23	4:1	17	354 (780)
	12.7 (.500)	4.3 (.169)	9.5	30	3:1	20	431 (950)

5.1.5 Threaded Metal Inserts

Where a screw connection is to be used, a threaded metal insert may give a stronger joint than could be obtained with a self-tapping screw. It is important to design the insert to minimize creation of molded-in stresses while maximizing pull-out 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 Celanese's polyester resins, including spin welding, thermal fusion or hot plate welding and ultrasonic welding.

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 intended mating surface of 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 on the same axis as the mating part and at a level that will allow the mating part to be brought down into firm contact with it. The raising and lowering mechanism should 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 joined parts immediately thereafter.

Fig. 5.5 • Simple Spin Welding Apparatus

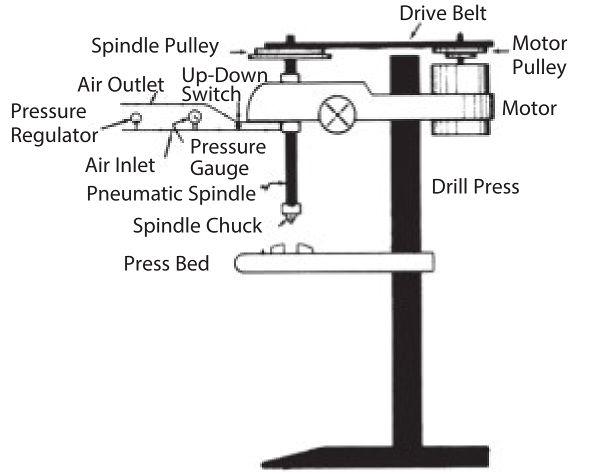


Fig. 5.6 • Pivot Tool with Flash Trimmer

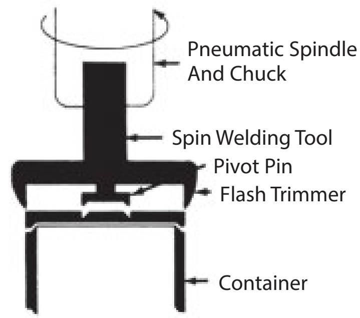
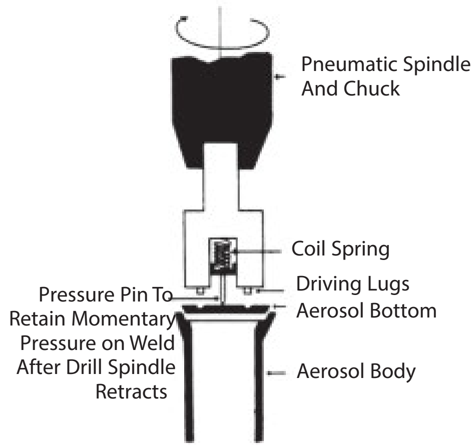


Fig. 5.7 • Driving Tools for Spin Welding



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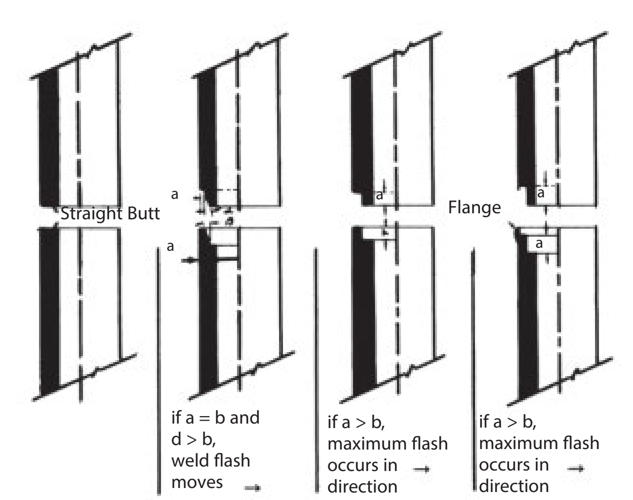
Spin welded joints may have other than flat 90° mating surfaces. The joint surface may be angled, stepped or profiled. Some examples of possible joint configurations for hollow structures are shown in Figure 5.8. Angled or profiled joints can retain flash and provide added weld surface for greater strength.

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.

Thermal fusion welding generates flash at the joint line and its 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, its volume should be great enough for flash collection. 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 of the final assembly. Generally, about 0.5 mm (0.02 in) per side of displacement may be expected. The mating part surfaces should be flat, clean of foreign material and dry. Typical platen tempera-tures for

Fig. 5.9 • Thermal Fusion Welding

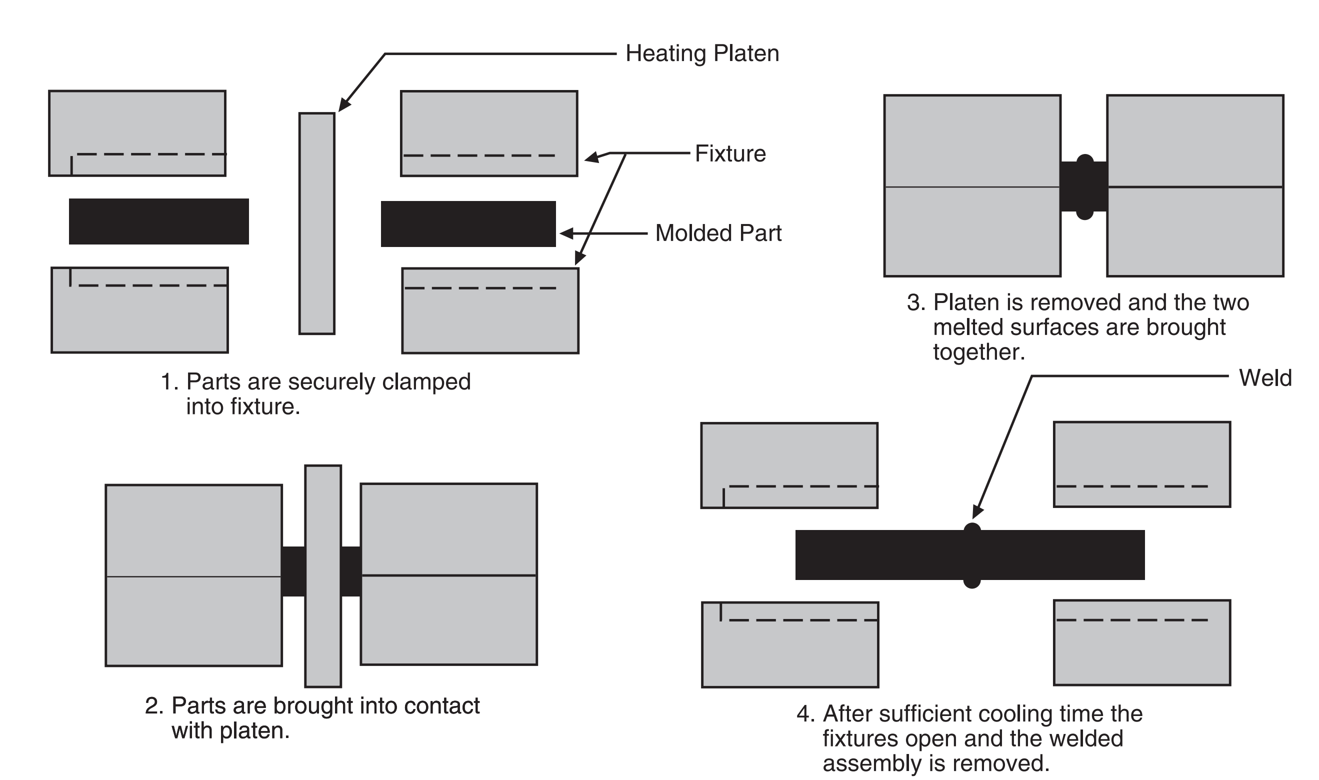


Fig. 5.10 • Typical Thermal Fusion Weld Joint Designs

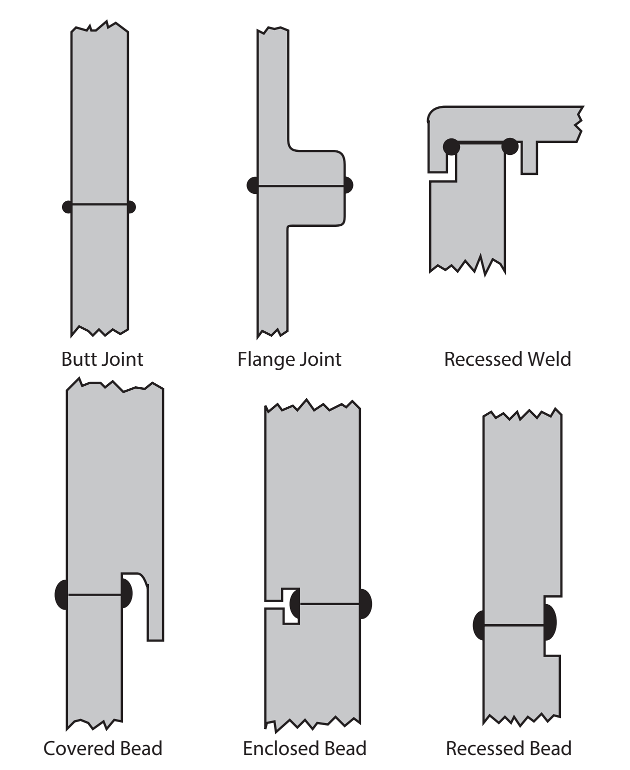


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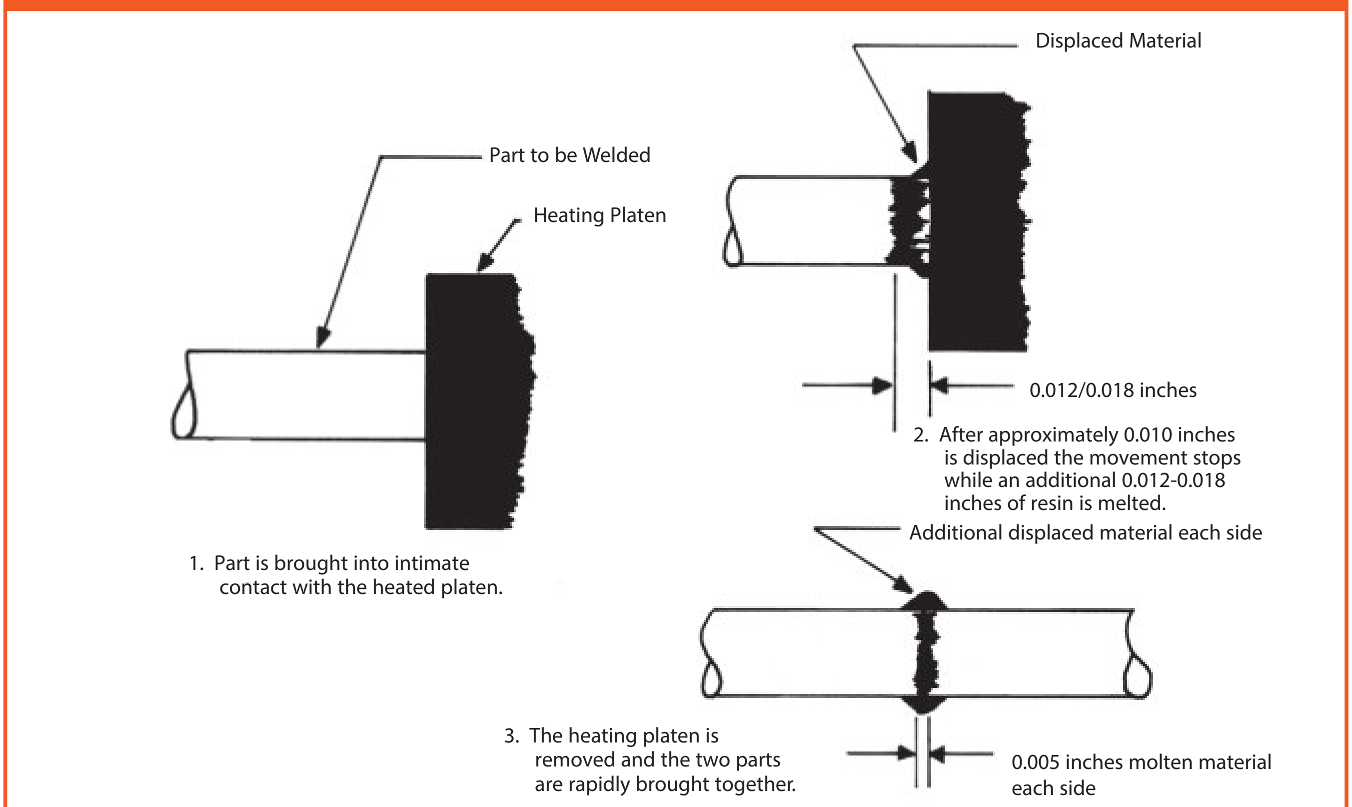
Fig. 5.11 • Heating the Plastic Resin for Welding



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Polyester resins have relatively sharp crystalline and freezing melting points and these transitions occur fairly quickly. Accordingly, the distances moved and the time required should be kept as short as possible in order to achieve the best weld strength. Under optimal conditions, about two-thirds of the molten resin should flow from the joint, i.e., 0.3 mm (0.01 in) when plasticized to a depth of 0.4 mm (0.015 in). As the weld cools, a holding pressure of 100-140 kPa (15-35 psi) is generally acceptable.

5.2.3 Ultrasonic Welding

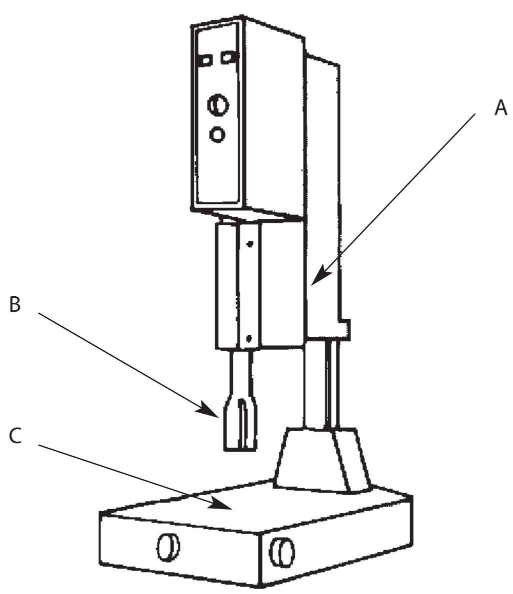
This quick and economical joining method gives good results when joining parts made from chemically compatible materials with similar or equivalent melting characteristics. As shown in Figure 5.12, a typical ultrasonic welding unit provides for generation and control of high frequency vibrational energy 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 so as to very quickly produce melting by frictional heating. The melt area is extended as the parts are telescoped together by the welding unit and a strong bond is formed thereby. A shear joint, as shown in Figure 5.13, is the preferred way to achieve a melt interface to completely fill the space between the mating surfaces. Shear joint interference guidelines for polyester parts are given in Table 5.2.

Table 5.2 • Interference Guidelines for Polyester Shear Joints

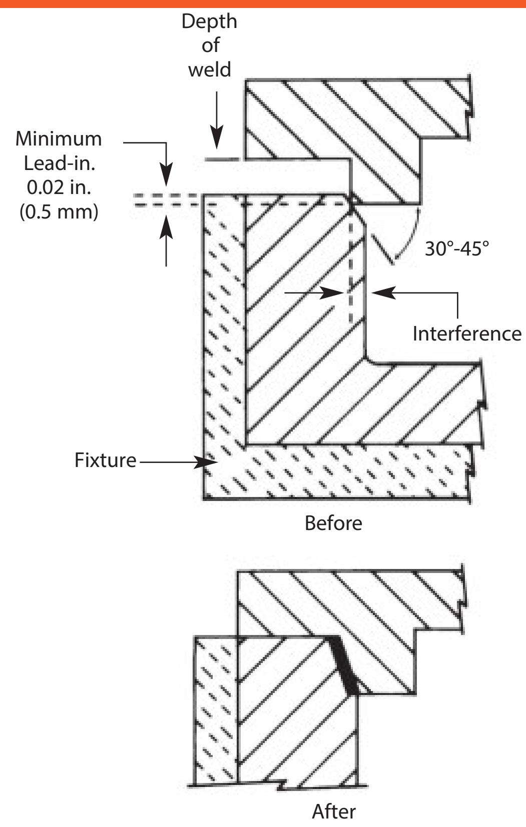
Maximum Part Dimensions, mm (in)	Interference Per Side, mm (in)	Part Dimension Tolerance, mm (in)
<18 (0.75)	0.2-0.3 (0.008-0.012)	±0.025 (0.001)
18-35 (0.75-1.50)	0.3-0.4 (0.012-0.016)	±0.050 (0.002)
>35 (1.50)	0.4-0.5 (0.016-0.020)	±0.075 (0.003)

Fig. 5.12 • Typical Ultrasonic Welding Equipment



(A) Ultrasonic Assembly Stand
(B) Horn
(C) Work Piece Area

Fig. 5.13 • Recommended Shear Joint Configuration



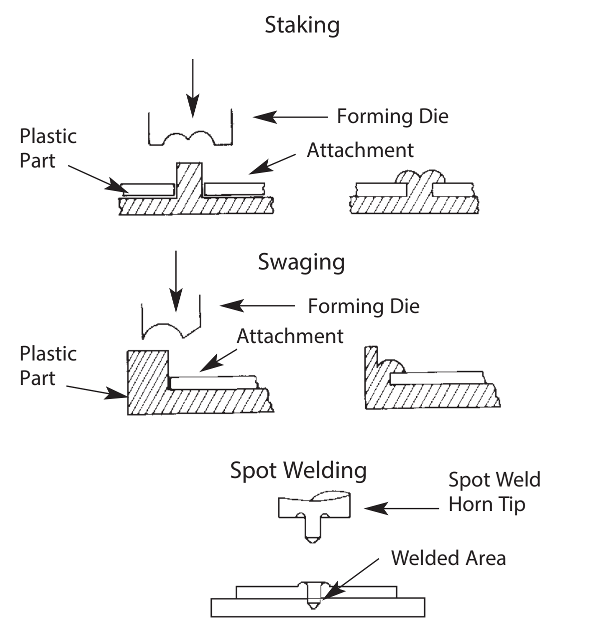
To obtain satisfactory high-quality welded joints, take account of the following factors:

- 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.
- 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. 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 assembly and ability 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.

Fig. 5.14 • Ultrasonic Staking, Swaging and Spot Welding



5.2.4 Adhesive Bonding

Parts molded from Celanese's polyester resins 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. The good chemical resistance of PBT and PET polymers inhibits attack by most solvents, so 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. As with adhesive bonding of materials in general, the surfaces should be closely mated so that the adhesive layer is thin. Common adhesives that may be used to bond parts made from Celanex® PBT, Impet® PET and Vandar® PBT alloys 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 its manufacturer.

5.3 Machining

Parts made from Celanese's polyester resins 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.

- Use only sharp tools
- Provide adequate chip clearance
- Support the work properly, especially for softer grades
- Provide adequate cooling, especially for softer grades
- Carbide tools may last longer when machining glass-reinforced or filled grades

5.3.1 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, 3,000 to 4,000 rpm, for instance
- Feed at 10-15 fpm (3.0-4.5 m/min)
- Use extra-wide gullets for chip clearance
- For sections less than .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 .5 inch (12.7 mm), use water cooling on the cutting area
- For softer Vandar® PBT alloy grades, cool the surface and hold the cut open if required

5.3.2 Drilling

- Run at 1,000-3,000 rpm and feed as fast as possible. Speeds above 3,000 rpm may melt the plastic
- Support the workpiece firmly during drilling
- Clear deep holes frequently – every .25 inch (6.4 mm) of bit travel
- Cool with an air jet or water-based coolant aimed into the hole
- For softer Vandar PBT alloy grades, using oversized bits at low rpm or 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

5.3.3 Turning

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

5.3.4 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

5.3.5 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 (245-305 m/min) and carbide burrs at around 2000 fpm (610 m/min)

5.4 Surface Treatment

A variety of surface treatments may be used with the polyester materials, including dyeing, painting, hot stamping, in-mold decorating, sublimation printing and laser marking.

5.4.1 Painting

Painting may be done with commercially available coating systems. Bake temperatures should be adjusted downward for the softer Vandar® PBT alloy grades. Some small amount of further shrinkage or warpage may occur during baking. Coating systems typically employ a primer and a top coat, 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 polyester grade being used. 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 parts made from Celanese's polyester resins. These methods include offset printing, silk screening, pad printing, sublimation printing and laser marking. Because of the wide range of compositions available from the three polyester product families, any printing method should be evaluated by printing a test plaque before committing to a production method.

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 glossy 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. Colors such as yellow, tan, blue and gray have all been used successfully in laser marking applications. As presented in Table 1.1, special grades are available for laser marking use.

5.4.5 Sterilization

Standard sterilization processes such as gamma radiation, ethylene oxide and steam autoclave may be used with Celanese's polyester resins. Sample testing should be done prior to exposure to autoclave temperatures of mechanically loaded parts made from unfilled resin grades.

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Engineered Materials

- Celanex® thermoplastic polyester (PBT)
- Hostaform® and Celcon® acetal copolymer (POM)
- 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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