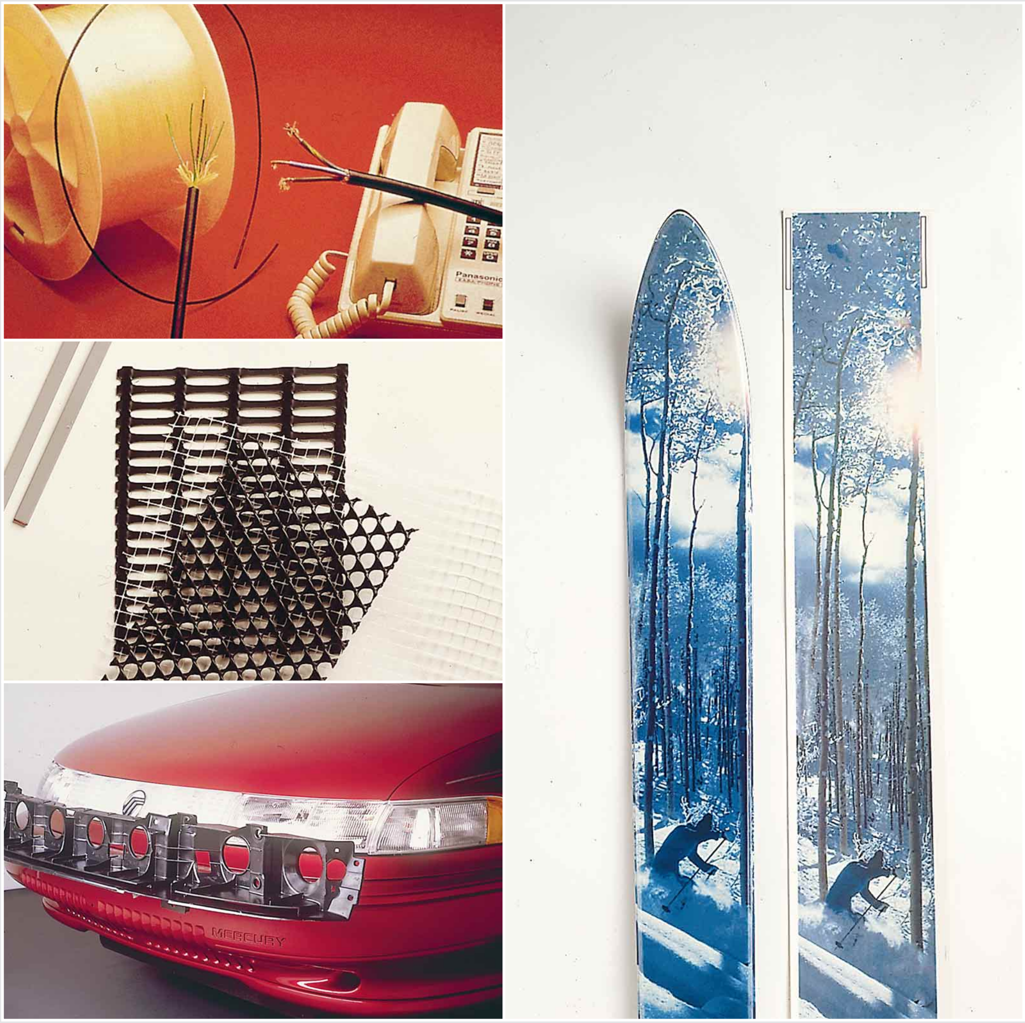
Ticona

Designing with Celanex®, Vandar®, Impet® & Riteflex®
Thermoplastic Polyesters

Design Manual (PE-10)



Foreword

This manual is written for parts designers, material engineers, mold designers and others wishing to take advantage of the unique and desirable features of the following product lines available from Ticona.

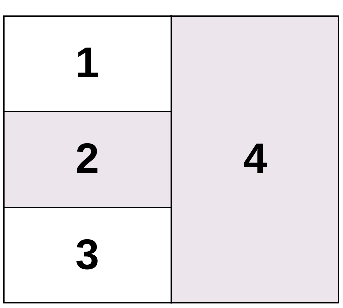
- Celanex® Thermoplastic Polyesters
- Vandar® Thermoplastic Polyester Alloys
- Impet® Thermoplastic Polyesters
- Riteflex® Thermoplastic Polyester Elastomers

This manual covers the basic structure and product characteristics of the thermoplastic polyester product line and its physical, thermal, mechanical, and electrical properties. Dimensional stability, creep and other long term properties, and resistance to the environment (including chemical resistance) are also discussed. Mold design criteria, assembly methods, and secondary operations on machining and finishing complete the brochure.

More information on specific grades, product properties, general plastic design principles, and processing and troubleshooting is available in the “Reference Publications” listed on page 1-7.

Material Safety Data Sheets (MSDS) provide valuable safety, health, and environmental information. **Before processing any of the products mentioned in this manual, please read the information provided on the appropriate MSDS.** The Celanex®, Vandar®, Impet® and Riteflex® Processing and Troubleshooting Guide (PE-6) is an excellent source of information. They can be obtained by contacting your local sales office or by calling Customer Services at 1-800-526-4960.

For assistance with part design, materials selection, specifications, and molding, call Product Information Services at 1-800-833-4882.



Front Cover Key

1. Fiber Optic Tubes (molded in Celanex® Thermoplastic Polyester).
2. Netting, Fencing, Support Grids (formed in Riteflex® Thermoplastic Elastomer).
3. Grill Opening Retainers (molded in Impet® Thermoplastic Polyester).
4. Sublimation Printing (printed on Vandar® Thermoplastic Polyester Alloy).

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Overview

Introduction

Chapter 1 contains an overview of the four polyester product groups available from Ticona: Celanex® Thermoplastic Polyesters, Vandar® Thermoplastic Polyester Alloys, Impet® Thermoplastic Polyesters, and Riteflex® Thermoplastic Polyester Elastomers.

Celanex® Thermoplastic Polyesters

Polybutylene terephthalate (PBT), the polyester from which Celanex products are produced, is semi-crystalline and is commonly produced through a two-step process using 1,4-butanediol and dimethyl terephthalate (DMT). The base polymer can be compounded with various additives, fillers, and reinforcing agents. Because of their composition and crystallinity, these products exhibit a unique combination of properties, which include:

- High strength, rigidity, and toughness.
- Low creep (even at elevated temperatures).
- Outstanding resistance to high temperatures.
- Minimal moisture absorption.
- Exceptional dimensional stability.
- Resistance to a wide range of chemicals, oils, greases, and solvents.
- Excellent electrical properties.
- Excellent colorability.

Celanex PBT also offers outstanding processing characteristics including:

- Fast cycles.
- Absence of volatiles during processing.
- The significant advantage of accepting high levels of reprocessed product (up to 50% for certain grades).

Rigidity, heat resistance, creep resistance, and electrical properties are among the superior performance characteristics that differentiate Celanex thermoplastic polyester from other engineering thermoplastics.

Celanex resins are supplied in unreinforced grades and in grades reinforced with glass and glass/minerals. Flame retardant and lubricated versions are also available in both unreinforced and reinforced grades.

Note: *Lubricated grades facilitate mold release and maximize productivity. The “-2” or “-3” grade suffix denotes a lubricant.*

Unfilled grades offer a wide range of melt viscosities for excellent processing latitude. Parts molded from these grades have smooth surfaces, high strength, and very good chemical resistance. Products with a range of melt viscosities are available which allow a variety of extrusion techniques ranging from melt blown (non-woven) to rod and slab extrusion. Several grades (filled and unfilled) have superior hydrolytic stability for applications in hot, humid environments, such as fiber optic buffer tubes, brake cable linings, and automotive connectors.

Grades reinforced with glass have excellent strength and high modulus while maintaining easy processing characteristics. Several grades are rated V-0 in the UL 94 flammability test in part thicknesses as low as 0.7 mm (0.028 in). Parts molded from many of these grades are free of surface exudation.

Glass/mineral reinforced grades produce parts with high impact strength, low warp and excellent dimensional stability.

Vandar® Thermoplastic Polyester Alloys

Vandar products are thermoplastic polyester alloys possessing outstanding ductility and stiffness combined with the excellent chemical and environmental resistance properties of polyesters. These alloys are easy to mold and retain their impact strength down to -29°C (-20°F).

Vandar alloys are offered both unreinforced and formulated with glass fiber and minerals.

The unreinforced grades exhibit high impact while providing strength and stiffness. In addition to having improved impact characteristics, Vandar 8000 is rated V-0 in the UL 94 flammability test in part thicknesses as low as 0.85 mm (0.033 in).

The unreinforced and higher flexibility grades fill the property gap between standard thermoplastic polyesters and elastomers. Some grades of Vandar (9114, 9116, 9118, AB100) are typically used in air bag cover applications.

Glass reinforced grades offer high strength, stiffness, and toughness over a wide temperature range of -40°C (-40°F) to over 149°C (300°F).

In addition to good impact strength at room temperature, mineral reinforced Vandar 2122 has excellent dimensional stability and can be painted.

Impet® Thermoplastic Polyesters

Impet products are thermoplastic polyesters which can be made with up to 100% post consumer recycled polyethylene terephthalate (PET). They possess outstanding physical properties and superior thermal and chemical resistance.

Impet polyesters are ideal for high performance applications that require toughness, rigidity, exceptional dimensional stability, and excellent electrical properties, and where flame retardance is not a requirement.

Impet polyesters are reinforced with glass fibers or with combinations of glass/mineral fibers.

Glass reinforced grades possess good thermal stability, good mechanical properties, and a high degree of toughness.

The glass/mineral grades combine strength, stiffness, warp resistance, and high temperature capability together with excellent processibility (high flow) during molding.

High impact grades are available under the name Impet HI thermoplastic polyesters. Impet HI 430U is an ultraviolet-light resistant grade.

Riteflex® Thermoplastic Polyester Elastomers

Riteflex products are a family of copolyester polymers which combine many desirable features of thermoset elastomers with the processing ease of engineering plastics. These products are tough, tear and flex fatigue resistant, and perform over a wide temperature range of -40 to 121°C (-40 to 250°F).

Riteflex elastomers are resistant to many chemicals including acids and bases, common solvents, oils, and greases. They are also abrasion resistant.

Riteflex elastomers are available as unreinforced specialty polymers in a wide range of Shore D hardnesses. The harder versions exhibit enhanced heat and chemical resistance while the softer materials possess good low temperature mechanical properties.

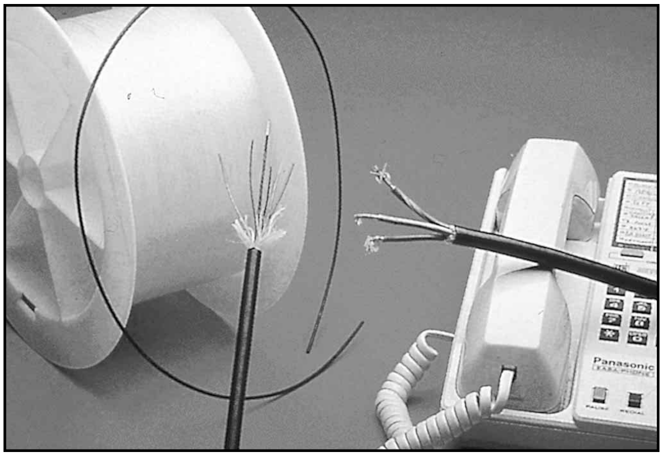
Typical Product Applications

Celanex, Vandar, Impet and Riteflex products have been successfully used in a wide range of industrial and consumer applications. These include appliances, automobiles, electrical and electronic devices, furniture, lawn and garden components, and recreational equipment. Typical product applications are listed in Table 1.1 and illustrated on pages 1-4 and 1-5.

For more information on any specific application, contact your local Ticona sales office or call Product Information Services at 1-800-833-4882.

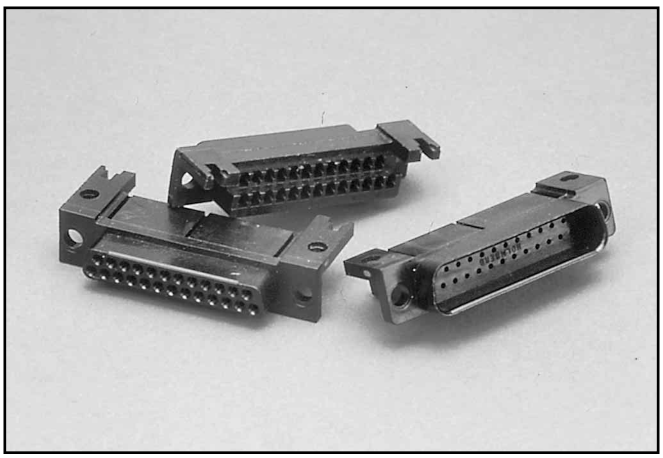
Table 1.1 Typical Product Applications

Product	Type	Typical Applications
Celanex	Unreinforced – General Purpose, Flame Retardant and Specialty Polymers	Keycaps, Cable Liners, Switches, Motor End Caps, Paint Brush Bristles, Stator Insulation, Filter Media, Fiber Optic Buffer Tubes, Gears, Electrical Connectors.
	Glass Reinforced, General Purpose	Automotive Distributor Caps, Motor Housings, Exterior Components, Coil Bobbins and Coil Cases, Appliance Housings, Rotors.
	Glass Reinforced, Flame Retardant	Connectors, DIP Sockets, Motor Components, Stator Insulation, Bobbins, Switches, Brush Holders, CRT Sockets, Terminal Boards.
	Glass Reinforced, Improved Impact	Pump Housings, Impellers, Power Tool Components, Tool Housings, Winch Housings, Electrical Parts, Power Distribution Systems.
	Glass Reinforced, Improved Surface Finish	Appliance Housings, Door Handles, Appliance Bases.
	Glass/Mineral Reinforced, Low Warp	Fan Blades, Shrouds, Appliance Housings, Automotive Exterior Panels.
	Glass/Mineral Reinforced, Low Warp, Flame Retardant	Switches, Bobbins, TV Transformers, Circuit Breakers.
Vandar	Unreinforced, Flame Retardant	Telephone Line Splice Cases, Switches, Connectors, Housings.
	Unreinforced, Improved Impact	Brake and Fuel Line Clips, Wheel Covers, Headlamp Bezels and Covers, Panels, Power Distribution Boxes.
	Unreinforced, Cold Temperature Impact	Air Bag Doors, Automotive Safety Systems, Wheel Covers, Fascias.
	Glass Reinforced, Improved Impact	Appliance Lids, Power Tools, Panels, Housings.
Impet	Unreinforced, Specialty Polymers	Film, Packaging, Fiber.
	Glass Reinforced, General Purpose	Windshield Wiper Brackets, A/C and Heater Duct Doors.
	Glass/Mineral Reinforced, Low Warp	Grill Opening Retainers, Throttle Body Cover.
Riteflex	Unreinforced, Specialty Polymers	Hose, Tubing, Seals, Gaskets, Belts, Pump Diaphragms, Energy Absorbing Devices, Coil (Wire) Coating, Hooks, Fasteners, Film, Sheet, Electrical/Electronic Connectors, Nonwoven Fabric, Footwear, Hardware, Polymer Modification, Monofilament.



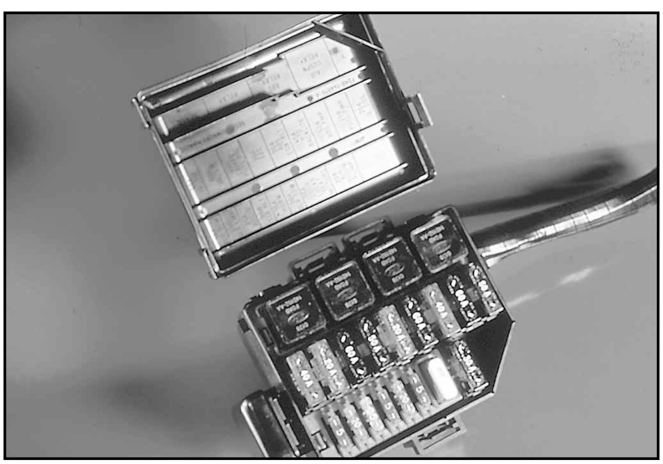
Celanex® 2001 was chosen as the material for fiber optic buffer tubes (shown in multiple colors) because its consistent viscosity makes it easy to process.

This engine cover is molded in Impet® PET. Impet resins contain up to 100% post-consumer recycled PET. Impet grades provide strength, chemical and heat resistance as well as excellent surface appearance.

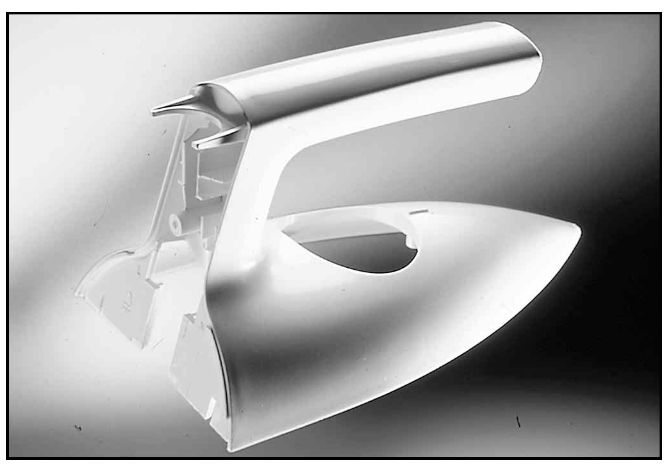


Celanex® 16 Series PBT grades are easily processed flame retardant and thermally stable. They are an excellent choice for under-the-hood automotive, electrical/electronic and industrial applications.

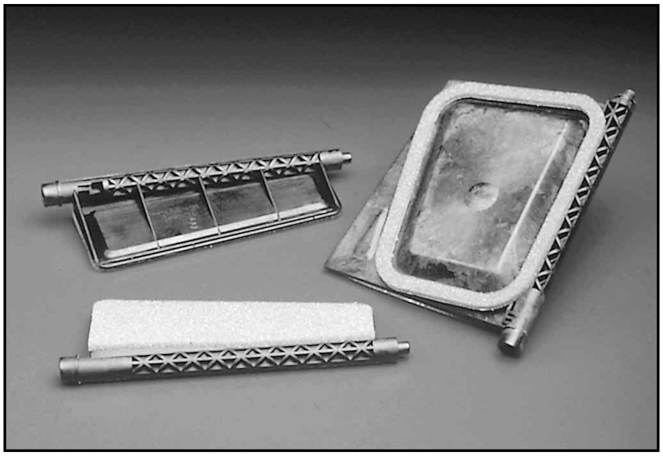
Celanex® 6500, a 30% glass/mineral filled PBT/PET alloy was used to mold these airfoil/wiper covers. UV resistance, stiffness and appearance were required for this application.



Temperature resistance, toughness and chemical resistance are a few of the properties that recommend Vandar® PBT polyester alloys for under-the-hood automotive applications such as this power distribution box.

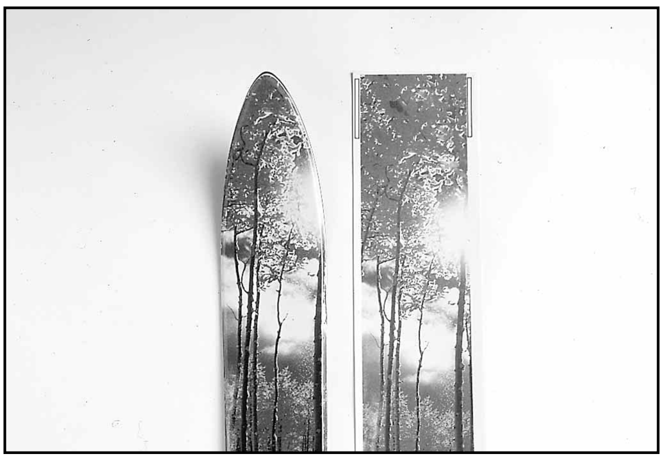


Celanex® PBT is ideal for household appliances where appearance, temperature resistance, dimensional stability and ease of processing are important.

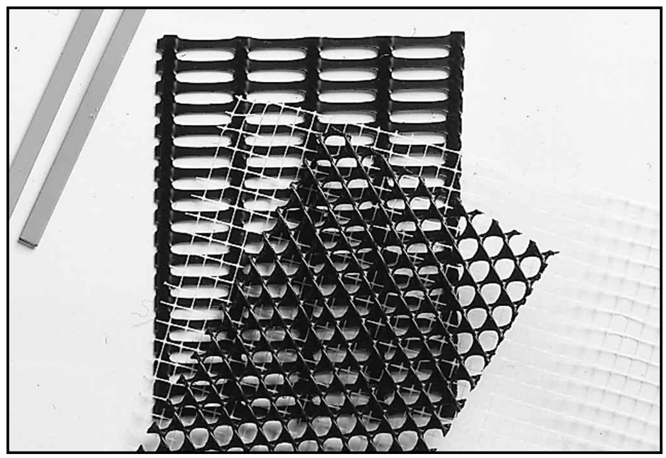


Duct vent doors molded in Impet® 340R recycled content PET from Ticona preserved the flatness essential to automotive heating, ventilating, and air conditioning systems.

Appliance knobs molded in Celanex® PBT exhibit excellent surface appearance, heat resistance and chemical resistance to foods and household chemicals.



Vandar® 2100 is especially well suited for sublimation printing to achieve bold, bright colors that are highly durable, even under heavy wear conditions.



Riteflex® polyester elastomer can be extruded, then stamped, to form a variety of shapes for applications such as netting, fencing and support grids.

Ford chose Impet® 830R for grille opening retainers (GOR) on their Mercury Sables because of its excellent combination of strength, stiffness, warp resistance, and high temperature capability together with excellent processibility (high flow) during molding.

This sandwich maker molded in glass filled Celanex® PBT has excellent surface appearance as well as temperature resistance and toughness.

Regulatory Codes and Agencies

Many grades of thermoplastic polyesters are in compliance with a variety of agency specifications and regulatory standards as shown.

Not all grades are covered by all regulatory codes and agencies. Call Product Information Services at 1-800-833-4882 for current information. A partial listing is in Table 1.2.

Table 1.2 Regulatory Codes and Agencies

Agency	Scope	Product/Grade	Classification
Canadian Standards Association (CSA)	CSA flammability and thermal ratings	Celanex 2016, 3114, 3116, 3126, 3200-2, 3210-2, 3216, 3226, 3286, 3300-2, 3310-2, 3311-3, 3414, 3316, 4300, 4330, 7316, 7700, Vandar 8000, 8001	PBTP
Food and Drug Administration (FDA)	Food contact applications conforming to 21 CFR 177.1660	Celanex 1300A, 1400A, 1600A, 1700A, 2000, 2000-2, 2000-3, 2002, 2002-2, 2002-3, 2003, 2003-2, 2003-3, 2008, 3200, 3200-2, 3300, 3300-2, 3400-2	
	Food contact applications conforming to 21 CFR 177.1590 and 21 CFR 177.2600	Riteflex, 635, 640, 647, 655, 663, 677	
Military Specifications	MIL-P 46161 (MR) “Plastic Molding Material, Polyterephthalate Thermoplastic, Glass-Fiber Reinforced”.	Celanex 3200, 3200-2	Grade B, Class 2
		Celanex 3300, 3300-2, 3310-2	Grade A, Class 3
	MIL-E 5272C ASG. “Fungus Resistance Test”.	Celanex 3210-2	Passed
		Celanex 3300, 3300-2, 3310-2	Passed
	MIL-M 24519 (Navy). “Molding Plastics, Electrical Thermoplastic”.	Celanex 3112-2, 3212-2	GPT-15F
		Celanex 3210, 3210-2, 3211-3	GPT-20F
		Celanex 3310, 3100-2, 3311-3, 3312-2, 3313-2, 3314, 3316	GPT-30F
	MIL-STD-810b-508 for fungus resistance conforming to soil burial requirements of Government Specification CCC-T-191-b-5762.	Celanex 3300	
National Sanitation Foundation (NSF)	Plumbing components for contact with potable water conforming to NSF Standard 14.	Celanex 1462Z, 1600A, 1602Z, 2000-2, 2000-3, 2002-2,2002-3, 2003-2, 2003-3, 3200-2, 3300-2	
	Plumbing components for contact with potable water conforming to NSF Standard 61.	Celanex 1462Z, 1600A, 1602Z, 1700A, 2000-2, 2000-3, 2002-2, 2002-3, 2003-2, 2003-3, 3200-2, 3300-2	
Underwriters Laboratories Inc. (UL)	UL flammability and relative thermal index (RTI) ratings.	See Table 2.4 in Chapter 2.	
	Ground insulation system-approval for certain bobbin insulation systems. Approvals and data are contained in UL File No. E60824 which can be released by UL on request to Ticona. This minimizes the cost and time of customer thermal aging programs which would normally be necessary to qualify new bobbin insulation systems.	Celanex 1602F, 1602Z, 2004-2, 3200-2	Class 130 (Class B)
		Celanex 1452F, 1462Z, 2012-2, 2016, 3116, 3126, 3210-2, 3210E, 3216, 3226, 3300-2, 3310-2, 3310E, 3311, 3314, 3316, 5200, 5300, 6400, 7700	Class 155 (Class F)
United States Dept. of Transportation (DOT)	Burn rate testing in accordance with Motor Vehicle Safety Standard (MVSS) 302.	See Table 2.5 in Chapter 2.	
United States Pharmacopoeia (USP)	Compliant with Class VI.	Celanex 2000-3, 2002, 2002-2, 2002-3, 2008	

Product Support

In addition to the reference publications listed on this page, assistance is available for part design, mold flow characterization, materials selection, specifications, and molding trials. For further help, call Product Information Services at 1-800-833-4882.

Computer Aided Assistance

Computer aided design, engineering, and manufacturing (CAD, CAE, and CAM respectively) have been applied to mold design, part design, and processing with significant improvement in production and accuracy. These technologies have also contributed to the increased use of thermoplastics in complex applications, many of which could not be handled with manual analysis techniques. For more information, contact your Ticona representative or call Product Information Services at 1-800-833-4882.

Safety and Health Information

The usual precautions when working with hot molten plastics must be observed in processing thermoplastic polyesters.

Before handling and/or processing any of the products mentioned in this manual, obtain and read the appropriate Material Safety Data Sheet (MSDS) for detailed safety, health, and environmental information. MSDS sheets can be obtained by contacting your local sales office or by calling Customer Service at 1-800-526-4960.

Use process controls, work practices, and protective measures described in the MSDS sheets to control workplace exposure to dust, volatiles, etc.

Reference Publications

More information on thermoplastic polyesters is available in the following Ticona publications. These can be obtained by contacting your local sales office or by calling Product Information Services at 1-800-833-4882.

- Designing With Plastic: The Fundamentals (TDM-1)
- Celanex® Thermoplastic Polyester - Short Term Properties (CX-4)
- Celanex® "16" Series Polyesters
- Vandar® Thermoplastic Alloys - Short Term Properties (VN-4)
- Impet® Thermoplastic Polyester - Short Term Properties (IP-4)
- Riteflex® Thermoplastic Polyester Elastomer - Short Term Properties (RF-4)
- Celanex®, Vandar®, Impet®, and Riteflex® Thermoplastic Polyesters - Processing and Troubleshooting Guide (PE-6)

Physical and Thermal Properties

Crystallinity

Celanex®, Vandar®, Impet®, and Riteflex® thermoplastic polyesters are semi-crystalline containing amorphous and crystalline regions. Molding temperatures significantly affect the degree of crystallinity of molded parts, which, in turn affect performance. Mold temperatures should be adjusted to obtain optimal performance. In most cases, this can be accomplished by using the mold temperatures listed below as the starting point.

- 66°C (150°F) for Celanex polyesters and glass-filled Vandar polyesters
- 93°C (200°F) for Impet polyesters
- 38°C (100°F) for Riteflex polyesters and unfilled Vandar® polyesters

For more specific recommendations on mold temperatures, refer to the publication titled "Celanex®, Vandar®, Impet®, and Riteflex® Thermoplastic Polyesters - Processing and Troubleshooting Guide (PE-6)."

Thermal Conductivity

Like other thermoplastics, Celanex, Vandar, Impet, and Riteflex polyesters, are thermal insulators and are slow to conduct heat. The addition of inorganic materials, such as glass fibers and minerals, may cause a slight increase in thermal conductivity.

Specific Heat

Specific heat is a parameter used in mold-flow calculations for processing and for part design. It measures the amount of heat energy necessary to increase the temperature of a given mass of material by one degree.

Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion (CLTE) is a measure of the linear change in dimensions with changes in temperature. CLTE for plastics is generally much higher than for metals. For CLTE values on various polyester grades, see Tables 4.1 through 4.4 in Chapter 4.

CLTE values can vary significantly with molding conditions and part geometry. Molded in stresses can affect expansion behavior. The value obtained in the flow direction can be different from the transverse direction. Actual parts may contain critical dimensions that are located in an area that is somewhere between the flow and transverse directions.

CLTE can be measured using a Thermal Mechanical Analyzer (TMA) by recording a plot of the dimensions of a specimen versus temperature. The slope of this curve over a selected temperature range or ranges is reported as the CTLE.

To compare the relative CLTE of materials a range of 23°C to 80°C was chosen as typical of many applications. However, this range crosses the glass transition temperature (Tg) of Celanex PBT, Impet PET and most Vandar Alloys. Caution must be used when applying a CLTE value where the temperature range crosses the Tg. At the Tg, there is usually a change in slope, so that the reported values are a hybrid of the slopes before and after the Tg. In many cases, the actual CLTE plot is more instructive than the reported CLTE values. Contact Product Information Services for further details.

Thermal Stability

Temperatures above the recommended melt temperatures should be avoided when processing Celanex, Vandar, Impet, and Riteflex polyesters. See the Polyesters Processing and Troubleshooting Guide (PE-6) for recommended processing temperatures.

At elevated temperatures, degradation of the material can occur releasing vapors which may be harmful. To avoid this potential hazard, always use proper ventilation in the molding area when processing polyesters.

Glass Transition Temperature (T_g)

At the glass transition temperature, T_g, a material undergoes a significant change in properties. Generally, below the glass transition temperature, the material has a stiff, glassy, brittle response to loads, while above the T_g, it has a more ductile, rubbery response. An approximate T_g range for PBT, PET and Riteflex 640 are shown in Table 2.1. The actual T_g measured may differ based on the method of measurement.

Melting Point

Thermoplastic materials become more fluid when temperatures increase. While crystalline materials have sharp, clearly defined melting points, amorphous and liquid crystalline thermoplastics soften and become more fluid over a wider range of temperatures. This property is of greater significance to molding and assembly operations than to product design.

Typical ranges for the melting point for various unreinforced and reinforced polyesters are shown in Table 2.2. For melting points on specific grades, contact your Ticona representative.

Table 2.1 Typical Glass Transition Temperatures

Product	Temperature Range, °C (°F)
PBT	40 - 50 (104 - 122)
PET	70 - 80 (158 - 176)
Riteflex 640	-60 (-76)

Table 2.2 Typical Melting Point Temperature Ranges

Product	Type	Temperatures, °C (°F)
Celanex	Unreinforced, General Purpose	220 - 225 (428 - 437)
	Unreinforced, Flame Retardant	
	Glass Reinforced, General Purpose	
	Glass Reinforced, Improved Impact	
	Glass Reinforced, Improved Surface Finish	220 - 252 (428 - 486)
	Glass/Mineral Reinforced, Low Warp	
	Glass/Mineral Reinforced, Low Warp, Flame Retardant	
Vandar	Unreinforced, Cold Temperature Impact	160 - 225 (320 - 437)
	Unreinforced, Improved Impact	220 - 252 (428 - 486)
	Unreinforced, Flame Retardant	
	Glass Reinforced, Improved Impact	
	Mineral Reinforced	
Impet	Glass Reinforced, General Purpose	241 - 252 (466 - 486)
	Glass/Mineral Reinforced, Low Warp	
Riteflex	All	160 - 220 (320 - 428)

Specific Gravity

The specific gravity is the ratio of the mass of a given volume of material compared to the mass of the same volume of water, both measured at 23°C (73°F). Since it is a dimensionless property, specific gravity values are conveniently used for comparing different materials to determine part cost and weight.

Table 2.3 contains typical specific gravity ranges for various unreinforced and reinforced polyesters. For specific gravity values on individual grades, refer to the appropriate short term properties brochure listed under “Reference Publications” in Chapter 1.

Table 2.3 Typical Specific Gravity Ranges

Product	Type	Specific Gravity
Celanex	Unreinforced, General Purpose	1.31
	Unreinforced, Flame Retardant	1.40 - 1.46
	15% Glass Reinforced, General Purpose	1.40 - 1.42
	30% Glass Reinforced, General Purpose	1.51 - 1.54
	15 - 30% Glass Reinforced, Flame Retardant	1.60 - 1.67
Vandar	Unreinforced, Flame Retardant	1.31
	Unreinforced, Improved Impact	1.20 - 1.25
	Unreinforced, Cold Temperature Impact	1.10 - 1.18
	Glass Reinforced, Improved Impact	1.30 - 1.47
	Mineral Reinforced	
Impet	Glass Reinforced, General Purpose	1.43 - 1.70
	13-45% Glass/Mineral Reinforced, Low Warp	1.40 - 1.72
Riteflex	Unreinforced	1.14 - 1.29

UL Flammability and Relative Temperature Index (RTI) Ratings

Flammability and RTI ratings for Celanex, Vandar, Impet, and Riteflex grades having Underwriters Laboratories (UL) recognition are listed in Table 2.4. UL "Yellow Cards" are available detailing recognition under File Numbers E45575, E93370, E174096 and 97ME40701.

RTI ratings are shown in Table 2.4 categorized under "Electrical Properties"; "Mechanical Properties With Impact"; and "Mechanical Properties Without Impact". These values are an estimate of the highest temperature at which a thermoplastic polyester can be exposed continuously, before losing 50% of its original property value over the estimated life of the molded part. This information is most useful when comparing the performance of different plastics.

The full UL Yellow Card may show additional RTI values at different thicknesses. Call Product Information Services for updated information or UL listings.

Note: RTI values should only be used as a guide.

Before selecting thermoplastic polyester, estimate the actual temperature that the part will encounter during service, as well as the critical mechanical and other properties for the specific application.

Table 2.4 UL Flammability and Relative Temperature Index Ratings - Partial Listing

Products	Grade	Color	Min. Thick. (mm)	UL 94 Flame Class	Relative Temperature Index (RTI) Electrical (°C)	Mechanical With Impact (°C)	Mechanical W/O Impact (°C)
Unreinforced, General Purpose							
Celanex	1400A	All	0.75	HB	140	120	130
	1600A	All	0.75	HB	140	120	130
	1700A	All	0.75	HB	130	—	130
	2000	All	0.71	HB	130	—	130
	2002	All	0.71	HB	130	—	130
	2003	All	0.71	HB	130	—	130
	2004	NC	1.0	HB	—	—	—
Unreinforced, Flame Retardant							
Celanex	2012-2	All	0.71	V-0	130	120	130
	2016+	All	0.75	V-0	130	120	130
	4016++	All	0.85	V-0	130	85	130
Vandar	8000+++	All	0.85	V-0	130	85	130
Unreinforced, Improved Impact							
Vandar	2100	GY	1.60	HB	75	75	75
Riteflex	635	NC, BK	1.50	HB	50	50	50
	640	NC, BK, YL	1.50	HB	50*	50	50
	647	NC, BK	1.50	HB	50	50	50
	655	NC, BK	1.50	HB	50*	50	50
	663	NC, BK	1.50	HB	50	50	50
	677	NC, BK	1.50	HB	50	50	50

NC - Natural Color GY - Gray BK - Black YL - Yellow

+ Virgin mixed with up to 50% regrind has the same basic material characteristics.
++ Virgin mixed with up to 25% regrind has the same basic material characteristics. In addition, virgin mixed with 26 to 50% regrind has the same flammability characteristics for natural, black and gray colors.
+++ Virgin mixed with up to 25% regrind has the same basic material characteristics. In addition, virgin mixed with 26 to 50% regrind has the same flammability characteristics in the natural color.
* Testing is in progress. Call Technical Information 1-800-833-4882 for latest information.

Table 2.4 UL Flammability and Relative Temperature Index Ratings (Continued)

Products	Grade	Color	Min. Thick. (mm)	UL 94 Flame Class	Relative Temperature Index (RTI) Electrical (°C)	Mechanical With Impact (°C)	Mechanical W/O Impact (°C)
Glass Reinforced, General Purpose							
Celanex	3100-2	All	0.71	HB	130	—	130
	3200-2	All	0.71	HB	130	—	130
	3300-2	All	0.71	HB	130	—	140
	3400-2	All	0.71	HB	130	—	140
Impet	330	All	0.75	HB	140	140	140
	340	All	0.81	HB	150	140	140
Glass Reinforced, Flame Retardant							
Celanex	3116+	All	0.81	V-0	130	—	130
	3126+	All	0.75	V-0	130	—	130
	3210-2	All	0.71	V-0	130	—	130
	3216+	All	0.75	V-0	130	—	130
	3226+	All	0.75	V-0	130	—	130
	3310-2	All	0.71	V-0	140	—	140
	3316+	All	0.75	V-0	140	—	140
Glass Reinforced, Improved Impact							
Celanex	1462Z	All	0.80	HB	130	130	140
	4300	All	0.71	HB	130	—	140
Vandar	4632Z	NC	1.50	HB	75	75	75
	4662Z	NC	1.50	HB	75	75	75
Glass Reinforced, Improved Surface Finish							
Celanex	5200-2	All	0.75	HB	130	—	140
	5300-2	All	0.71	HB	130	—	140
Glass/Mineral Reinforced, Low Warp							
Celanex	J600	NC, BK	0.82	HB	75	75	75
	6400-2	All	0.75	HB	130	—	—
Impet	630	NC, BK	0.75	HB	75	75	75
	740	BK	0.75	HB	140	140	150
Glass/Mineral Reinforced, Low Warp, Flame Retardant							
Celanex	7305	All	0.84	V-0	130	130	140
	7316	NC, BK	0.85	V-0	140	—	140
	7700-2	All	0.74	V-0	140	—	140
	7716	NC	0.90	V-0	—	—	—

NC - Natural Color   BK - Black

+ Virgin mixed with up to 50% regrind has the same basic material characteristics.
++ Virgin mixed with up to 25% regrind has the same basic material characteristics. In addition, virgin mixed with 26 to 50% regrind has the same flammability characteristics for natural, black and gray colors.
+++ Virgin mixed with up to 25% regrind has the same basic material characteristics. In addition, virgin mixed with 26 to 50% regrind has the same flammability characteristics in the natural color.

Table 2.5 provides burning rates for various types and grades of Celanex, Vandar, and Impet thermoplastic polyesters. These burning rates were obtained via testing in accordance with the US Department of Transportation (DOT) Motor Vehicle Safety Standard (MVSS) 302.

Table 2.5 Burning Rates of Various Polyesters

Type	Product	Grade	Sample Thickness mm (in)	Burn Rate mm/min (in/min)
Unreinforced, General Purpose	Celanex	2002	1.0 (0.040)	29.5 (1.160)
		602AC	1.0 (0.040)	21.3 (0.840)
Unreinforced, Cold Temperature Impact	Vandar	9118	1.0 (0.040)	18.4 (0.720)
		AB100	1.0 (0.040)	14.1 (0.560)
Glass Reinforced, General Purpose	Celanex	3200	1.3 (0.050)	25.4 (1.000)
		3300	1.3 (0.050)	33 (1.315)
		3400	1.0 (0.040)	28.9 (1.140)
Glass Reinforced, Flame Retardant	Celanex	3210	1.0 (0.040)	Self Extinguishing
		3216	1.0 (0.040)	Self Extinguishing
		3310	1.0 (0.040)	Self Extinguishing
		3316	1.0 (0.040)	Self Extinguishing
Glass/Mineral Reinforced, Low Warp	Celanex	6500	1.0 (0.040)	31.3 (1.230)
	Impet	610R	1.0 (0.040)	25.2 (0.990)

Mechanical Properties

Introduction

Parts made of Celanex®, Vandar®, Impet®, and Riteflex® thermoplastic polyesters have been used in a wide variety of industrial and consumer applications because of their advantages over metals and other thermoplastics. To take full advantage of the superior characteristics of these products, knowledge of their mechanical characteristics is essential. This chapter covers short term mechanical properties and long term characteristics which are time/temperature dependent and must be considered for proper part design.

For a general overview of principles and concepts of plastic part design, refer to the brochure titled “Designing with Plastic: The Fundamentals (TDM-1)” listed under “Reference Publications” in Chapter 1.

ISO Test Standards

Ticona has expanded its plastics testing and reporting of data to include ISO (International Organization for Standardization) protocols. This change will mean more reproducible and consistent test data for Ticona products. Where available, both ISO and ASTM data are provided in this manual.

Table 3.1 shows a partial listing of ISO/ASTM short term property data for representative polyester types. For additional ISO/ASTM data, refer to the appropriate short term properties brochures listed under “Reference Publications” in Chapter 1.

Note: ISO testing uses samples having different specimen geometry and different test conditions than ASTM. Therefore, ISO and ASTM test results may not be equivalent for the same plastic material, even when both results are expressed in metric units. For example, the ASTM tensile strength value for Celanex 2002 (shown in Table 3. 1) is 55.9 MPa (8100 psi); the corresponding ISO value is 60 MPa.

Table 3.1 ISO/ASTM Typical Properties Comparison for Representative Grades

			Celanex			
Property	**Test Method**	**Units**	**2002**	**3200**	**3300**	**4306**
ISO Data*						
Tensile Strength at Break	ISO 527	MPa	60	100	130	120
Flexural Strength	ISO 178	MPa	80	150	210	180
Flexural Modulus	ISO 178	MPa	2,500	5,200	9,700	8,500
Izod Impact Strength, Notched	ISO 180	kJ/m^2	5.0	5.0	7.5	12.0
Rockwell Hardness	ISO 2039-2		78	90	90	74
Deflection Temperature Under Load (DTUL) at 1.80 MPa	ISO 75	°C	55	195	205	164
ASTM Data*						
Tensile Strength at Break	D638	psi	8,100	13,500	19,500	17,500
Flexural Strength	D790	psi	12,500	21,000	28,000	26,000
Flexural Modulus	D790	psi	370,000	700,000	1,200,000	1,200,000
Izod Impact Strength, Notched	D256	ft lb/in	0.9	1.0	1.7	2.0
Heat Deflection Temperature (HDT) at 264 psi	D648	°F	131	378	403	338

* Except for DTUL/HDT, all test results are at 23°C (73°F).

Table 3.1 ISO/ASTM Typical Properties Comparison for Representative Grades (Continued)

Property	Test Method	Units	Celanex	Vandar		
			J-600	2500	4632Z	4662Z
ISO Data*						
Tensile Strength at Break	ISO 527	MPa	95	35	60	80
Flexural Strength	ISO 178	MPa	150	50	100	130
Flexural Modulus	ISO 178	MPa	11,000	1,500	3,800	6,700
Izod Impact Strength, Notched	ISO 180	kJ/m^2	5.1	NB	17	21
Rockwell Hardness	ISO 2039-2		73	104	109	112
Deflection Temperature Under Load (DTUL) at 1.80 MPa	ISO 75	°C	190	50	154	175
ASTM Data*						
Tensile Strength at Break	D638	psi	14,000	4,900	9,000	12,000
Flexural Strength	D790	psi	23,500	7,200	14,000	19,000
Flexural Modulus	D790	psi	1,500,000	210,000	500,000	925,000
Izod Impact Strength, Notched	D256	ft lb/in	1.3	NB	2.3	4.1
Heat Deflection Temperature (HDT) at 264 psi	D648	°F	380	125	309	374

* Except for DTUL/HDT, all test results are at 23°C (73°F).

Table 3.1 ISO/ASTM Typical Properties Comparison for Representative Grades (Continued)

Property	Test Method	Units	Vandar	Impet		Riteflex	Impet HI
			9116	330R	840R	655	430
ISO Data*							
Tensile Strength at Break	ISO 527	MPa	20	170	140	26	73
Flexural Strength	ISO 178	MPa	15	270	215	7.0	115
Flexural Modulus	ISO 178	MPa	400	11,000	15,650	235	4,200
Izod Impact Strength, Notched	ISO 180	kJ/m^2	NB	10	7.0	NB	18
Rockwell Hardness	ISO 2039-2		NA	100		Shore D 55	—
Deflection Temperature Under Load (DTUL) at 1.80 MPa	ISO 75	°C	43	224	218		141
ASTM Data*							
Tensile Strength at Break	D638	psi	2,750	23,500	19,800	3,650	9,800
Flexural Strength	D790	psi	1,650	35,000	28,600		16,000
Flexural Modulus	D790	psi	45,000	1,500,000	2,100,000	28,800	530,000
Izod Impact Strength, Notched	D256	ft lb/in	NB	1.5	1.2	NB	3.4
Heat Deflection Temperature (HDT) at 264 psi	D648	°F	—	435	429		286

* Except for DTUL/HDT, all test results are at 23°C (73°F).

Table 3.2 Miscellaneous Properties for Celanex® Thermoplastic Polyester

Property*	ASTM Test	Units	Grades 2000	2002	2012
Compressive Strength	D695	MPa	88	84	97
		psi	12,800	12,200	14,000
Compressive Modulus	D695	MPa	2,588	2,622	2,974
		10^6 psi	0.375	0.380	0.431
Shear Strength	D732	MPa	44	47	45
		psi	6,300	6,750	6,500
Tensile Impact Strength	D1822	kJ/m^2	29	57	21
		$ft\text{-}lb/in^2$	14	27	10
Taber Abrasion	D1044	mg/1000 cycles	13	14	—
Coefficient of Friction Against Metals, Dynamic	—	—	0.13	0.13	0.10 - 0.13
Coefficient of Friction Against Metals, Static	—	—	0.13	0.13	0.10 - 0.13

Table 3.2 Miscellaneous Properties for Celanex® Thermoplastic Polyester (Continued)

Property*	ASTM Test	Units	Grades 3200	3210	3211	3300
Compressive Strength	D695	MPa	—	117	124	124
		psi	—	17,000	18,000	18,000
Compressive Modulus	D695	MPa	—	—	5,520	4,830
		10^6 psi	—	—	0.800	0.700
Shear Strength	D732	MPa	48	55	67	56
		psi	6,900	8,000	9,700	8,100
Tensile Impact Strength	D1822	kJ/m^2	59	57	74	99
		$ft\text{-}lb/in^2$	28	27	35	47
Taber Abrasion	D1044	mg/1000 cycles	24	14	—	40
Coefficient of Friction Against Metals, Dynamic	—	—	0.10 - 0.21	0.10 - 0.13	0.12 - 0.16	0.12
Coefficient of Friction Against Metals, Static	—	—	0.15 - 0.19	—	0.18 - 0.23	0.16 - 0.34

*All test results are at 23°C (73°F).

Table 3.2 Miscellaneous Properties for Celanex® Thermoplastic Polyester (Continued)

Property*	ASTM Test	Units	Grades			
			3310	3311	3400	4300
Compressive Strength	D695	MPa	124	152	—	141
		psi	18,000	22,000	—	20,500
Compressive Modulus	D695	MPa	—	7,590	—	6,210
		10^6 psi	—	1.1	—	0.9
Shear Strength	D732	MPa	61	67	54	56
		psi	8,900	9,700	7,800	8,100
Tensile Impact Strength	D1822	kJ/m^2	101	105	116	114
		$ft\text{-}lb/in^2$	48	50	55	54
Taber Abrasion	D1044	mg/1000 cycles	40	—	18	29
Coefficient of Friction Against Metals, Dynamic	—	—	0.10 - 0.13	0.12 - 0.16	0.12 - 0.16	0.13 - 0.15
Coefficient of Friction Against Metals, Static	—	—	—	0.17 - 0.26	0.17 - 0.19	0.17 - 0.18

Table 3.2 Miscellaneous Properties for Celanex® Thermoplastic Polyester (Continued)

Property*	ASTM Test	Units	Grades		
			5300	6400	7700
Compressive Strength	D695	MPa	—	107	—
		psi	—	1,500	—
Compressive Modulus	D695	MPa	—	6,900	—
		10^6 psi	—	1.0	—
Shear Strength	D732	MPa	57	48	44
		psi	8,240	7,000	6,370
Tensile Impact Strength	D1822	kJ/m^2	95	40	42
		$ft\text{-}lb/in^2$	45	19	20
Taber Abrasion	D1044	mg/1000 cycles	17	25	—
Coefficient of Friction Against Metals, Dynamic	—	—	0.13	0.13 - 0.15	0.01 - 0.20
Coefficient of Friction Against Metals, Static	—	—	—	0.17 - 0.23	0.14 - 0.24

* All test results are at 23°C (73°F).

Table 3.3 Miscellaneous Properties for Celanex® Series 16 Thermoplastic Polyester

Property*	ASTM Test	Units	Grades			
			2016	3116	3216	3316
Compressive Strength	D695	MPa	94	103	115	125
		psi	13,695	14,888	16,702	18,160
Shear Strength	D732	MPa	44	49	52	57
		psi	6,438	7,047	7,525	8,318
Tensile Impact, 1/8" Thickness	D1822	kJ/m^2	104	101	117	130
		$ft\text{-}lb/in^2$	49.3	47.8	55.5	61.7
Coefficient of Friction (Kinetic) Against Steel	—	—	0.13	0.13	0.13	0.14
Against Brass	—	—	0.21	0.21	0.21	0.22
Against Aluminum	—	—	0.18	0.18	0.19	0.21

* All test results are at 23°C (73°F).

Short Term Mechanical Properties

Tensile and Elongation

Typical tensile stress versus strain curves, per ASTM D638 test conditions, are shown in Figures 3.1 through 3.3.

Note: Secant modulus-strain plots, generated from the stress-strain data, are also shown in Figures 3. 1 through 3.3. See "Secant Modulus" on page 3-9.

The stress-strain plots shown in Figure 3-1 are for various unreinforced grades of Celanex and Vandar. In Figures 3.2 and 3.3, stress-strain plots are shown for various reinforced grades of Celanex and Impet resins.

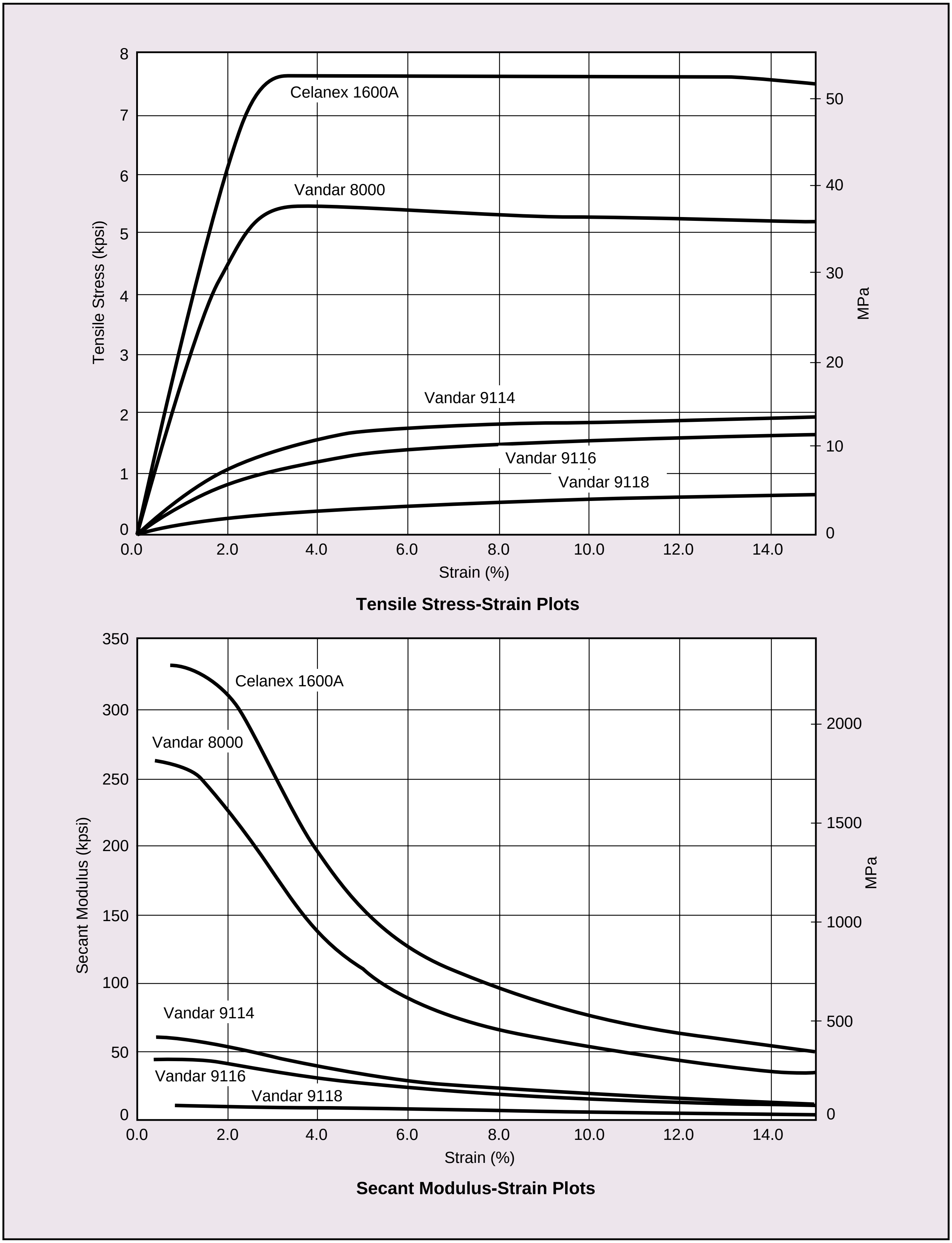


Figure 3.1 Typical Tensile Stress & Secant Modulus Plots for Some Unreinforced Grades of Celanex® Thermoplastic Polyester and Vandar® Thermoplastic Polyester Alloy

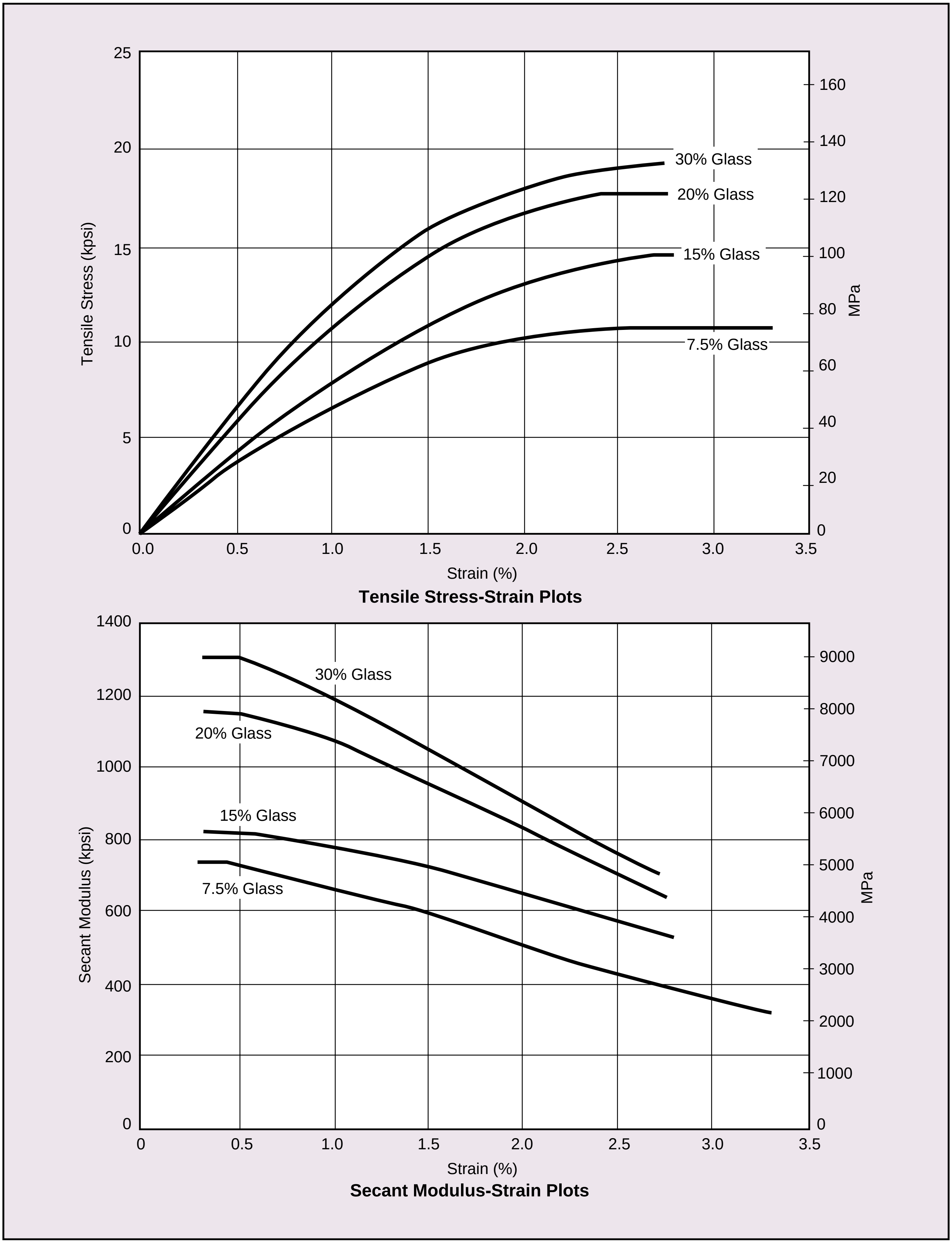


Figure 3.2 Typical Tensile Stress & Secant Modulus Plots, 7.5 to 30% Glass Reinforced Grades of Celanex® Thermoplastic Polyester

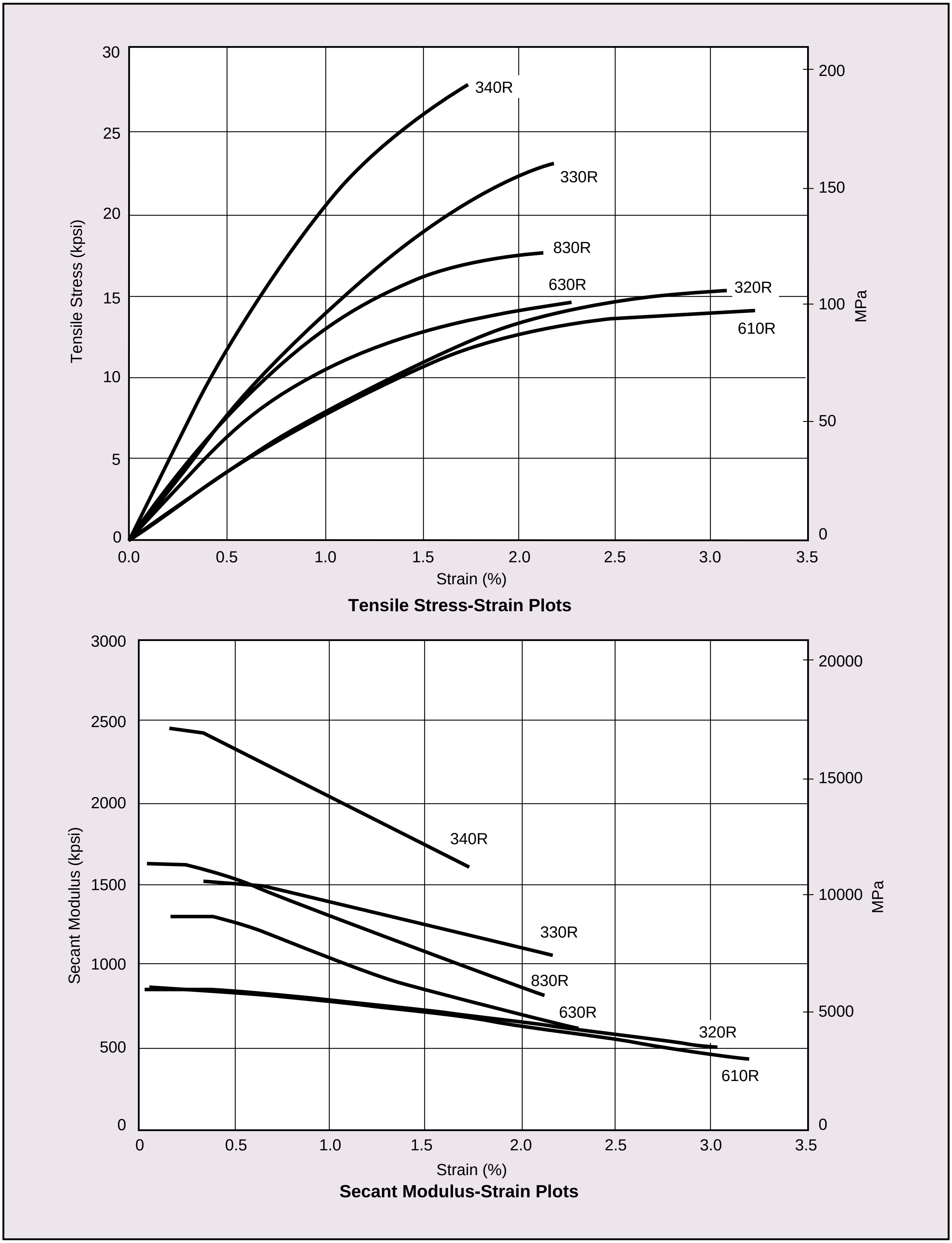


Figure 3.3 Typical Tensile Stress & Secant Modulus Plots for Glass and Glass/Mineral Reinforced Grades of Impet® Thermoplastic Polyester

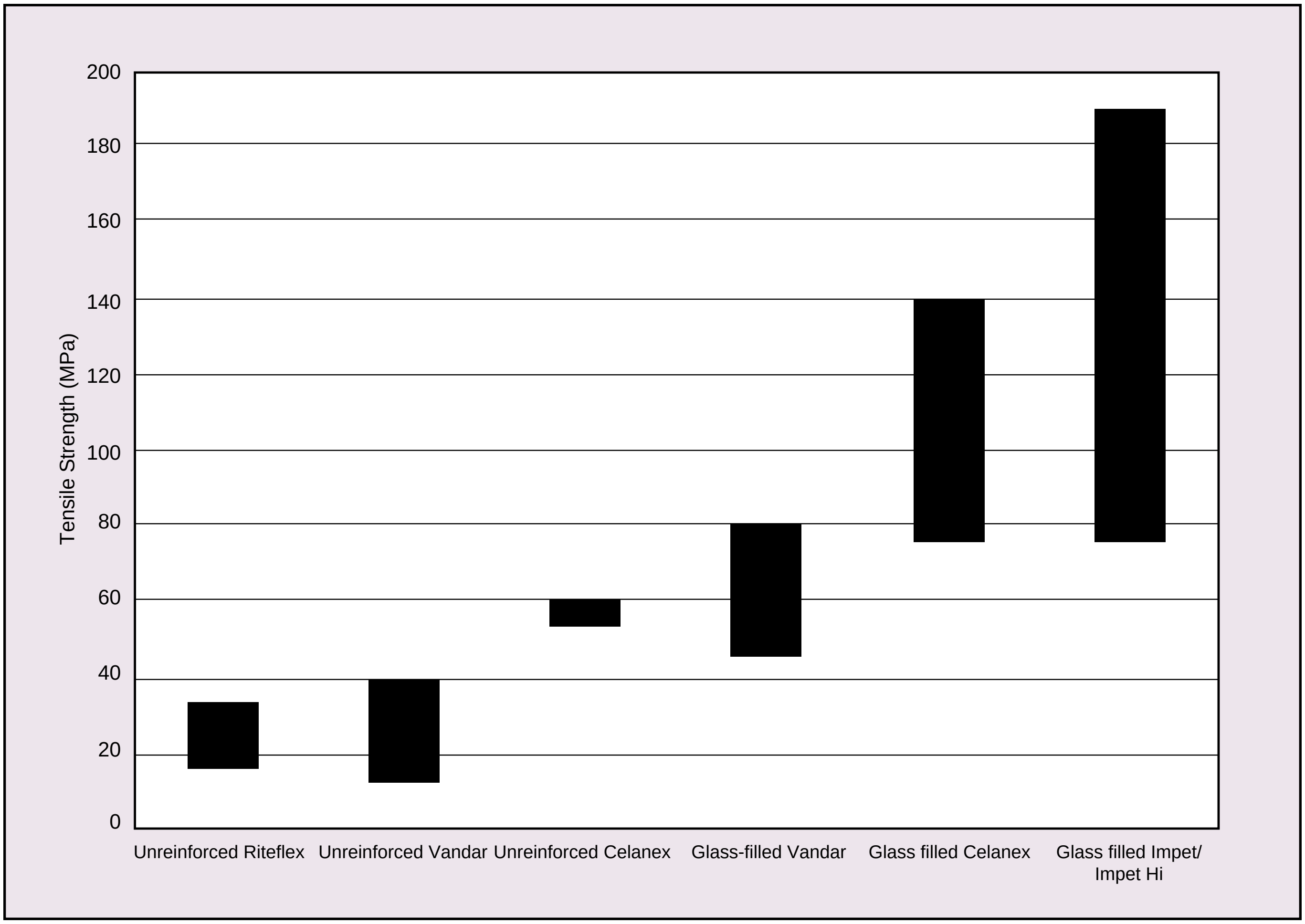


Figure 3.4 Typical Tensile Strength Range for Various Subcategories of Polyester Resins

Typical tensile strength ranges for various subcategories of Celanex, Vandar, Impet, and Riteflex polyesters are shown in Figure 3.4. Tensile strength values range from 18 MPa for unreinforced Riteflex to 190 MPa for glass filled Impet.

Elastic Modulus

Elastic modulus, generally reported for plastic materials, is either the tensile modulus or the flexural modulus according to ISO 178. Either tensile or flexural modulus may be used in design calculations calling for the elastic modulus (or Young's modulus).

Figure 3.5 illustrates typical flexural modulus values for various subcategories of Celanex, Vandar, Impet, and Riteflex polyesters. Flexural modulus values range from approximately 16,500 MPa for glass filled Impet Polyester, down to a low of about 700 MPa for unreinforced Riteflex elastomer.

Secant Modulus

The initial modulus is useful for a first approximation of polymer stress-strain values. According to ISO or ASTM test methods, either the tensile or flexural modulus value can be used. However, at strain values greater than 1.0% (at room temperature), a better approximation of stress can be obtained by using the secant modulus. The secant modulus is calculated by dividing the stress by the strain. See Figures 3.1 through 3.3 (on pages 3-6, 3-7, and 3-8) for secant modulus-strain plots generated from the stress-strain data on various unreinforced and reinforced grades of Celanex, Vandar and Impet.

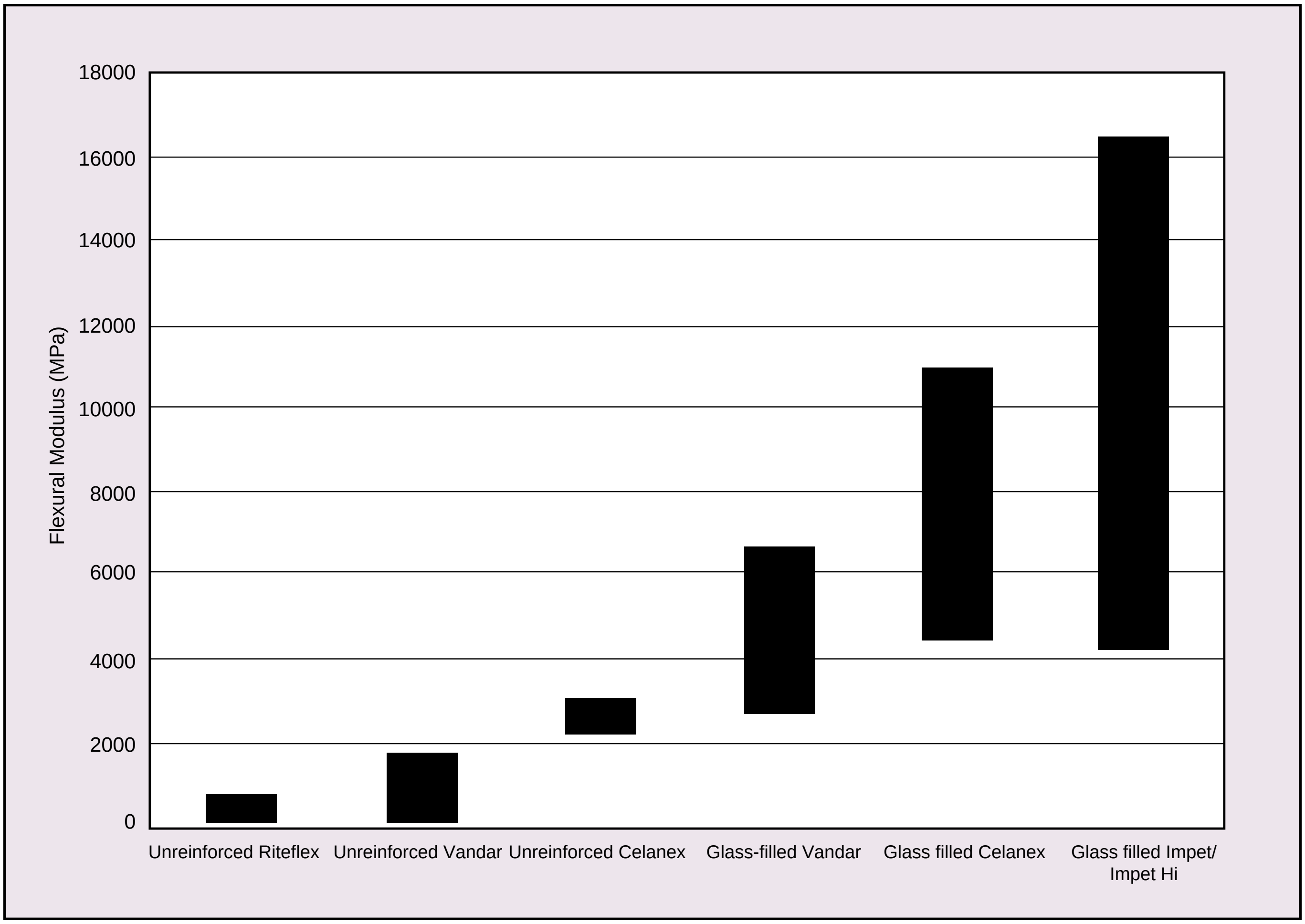


Figure 3.5 Flexural Modulus Range for Various Subcategories of Polyester Resins

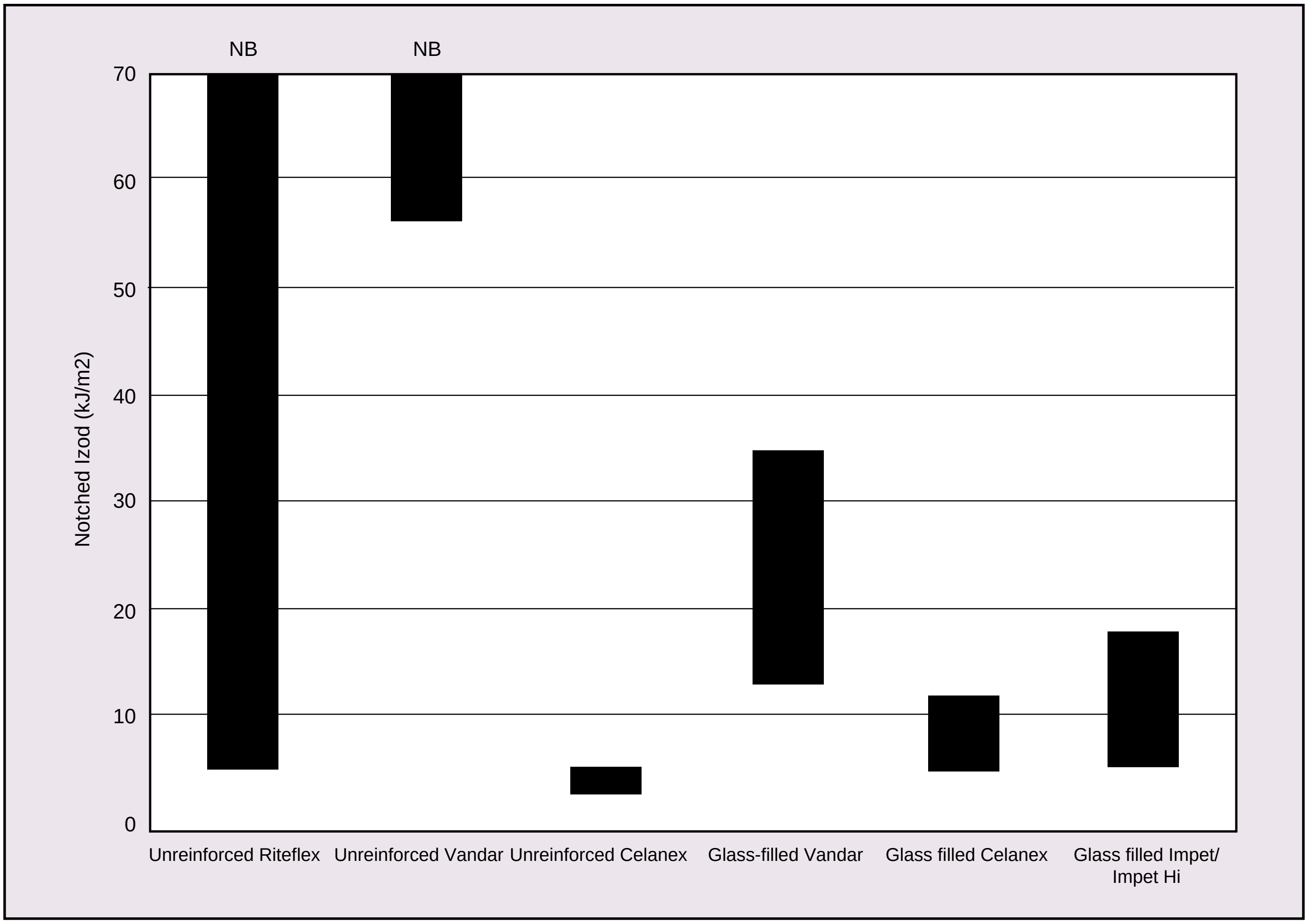


Figure 3.6 Typical Notched Izod Impact Strength Range for Various Subcategories of Polyester Resins

Notched Izod Impact

Although not directly used in design calculations, the Notched Izod Impact Test and similar impact tests are used as indications of material sensitivity to sharp corners and notches in molded parts. Figure 3.6 illustrates the typical Izod impact strength range for various subcategories of reinforced and unreinforced polyesters. For values on specific grades see CX-4, VN-4, IP-4 and RF-4 brochures.

Poisson's Ratio*

Poisson's ratio for most plastics falls between 0.30 and 0.40. Therefore, using a Poisson's ratio of 0.35 is generally adequate for most stress and deflection calculations requiring this value. At elevated temperature, a Poisson's ratio of 0.38 may be more appropriate.

Shear Modulus*

For general design calculations, the shear modulus can be obtained from the relationship between tensile modulus and Poisson's ratio using the following equation:

$$G = \frac{E}{2(1 + \nu)}$$

In this equation, "G" is the shear modulus, "E" is the tensile modulus, and "ν" is Poisson's ratio.

Shear Strength*

Shear strength values for some Celanex grades are provided in Table 3.2 (page 3-3). These values were obtained using the test conditions specified in ASTM D732.

Testing involves measuring the load as a round hole is punched in the specimen. As a result, the shear strength as measured includes contributions by bending and compressive forces. Therefore, when the shear strength is required, either the published shear strength or 1/2 of the tensile strength (whichever is smaller) should be used. Usually, this is adequate for most design calculations and generally applies to all grades of Celanex, Vandar, Impet, and Riteflex thermoplastic polyesters.

Weld Line Strength*

Weld line strength of thermoplastic polyesters approaches the strength of the base resin in well molded parts. To compensate for difficult mold flow conditions and complex design requirements, weld line strength should be conservatively estimated at 80 - 90% of the published tensile strength value for the corresponding unreinforced resin.

This conservative value is particularly critical for glass reinforced grades because the weld line strength is considerably below the tensile strength of the material in the flow direction, which is typically reported. This is due to the glass reinforcement not crossing the weld line. Contact your Ticona representative for information on weld line characteristics on specific grades.

Molding Effects

Information in this manual was generated for test samples molded at recommended processing conditions for various grades of polyesters.
For typical molding conditions, refer to the publication titled "Celanex®, Vandar®, Impet® and Riteflex® Thermoplastic Polyesters - Processing and Troubleshooting Guide (PE-6)."

Occasionally, part design criteria or processing equipment parameters such as gate size, melt temperature and mold temperature may require the molder to deviate from recommended conditions. Moreover, actual parts are usually more complex than laboratory tensile or flex bars. To maximize engineering performance, the designer, molder and raw materials supplier should work closely together to specify molding parameters based on actual part performance.

Anisotropy*

Most crystalline thermoplastic polyesters are anisotropic. They exhibit different properties (such as shrinkage) in the flow and transverse directions after molding.

Test results are based primarily on laboratory samples. Processing, mold filling and part design are typically very different from the "ideal" conditions used for test specimens. Therefore, molds should be cut steel safe and several shots should be taken before hardening the molds.

Another effect of anisotropy is seen in differences in mechanical properties. In some cases, the strength and modulus in the transverse direction can be as little as 50% of that reported in the machine direction.

However, when designing parts using glass reinforced grades, the literature values for strength and modulus of these grades should be reduced by approximately 25 - 35% to compensate for the effects of anisotropy. For round or cylindrical parts, less reduction is required. The anistropic effect is minimal in unreinforced grades.

Temperature Effects*

Short term property data sheets generally provide information only at room temperature. Other tests are needed to expand the thermal range of mechanical properties. Most useful for design is stress-strain measurements at various temperatures. Other tests, including Dynamic Mechanical Analysis (DMA), Deflection Temperature Under Load (DTUL) and Underwriters Laboratories (UL) Thermal Index Ratings, are used to compare or specify materials.

As a general rule, semi-crystalline products such as polyesters retain their mechanical properties under thermal stress to a greater extent than amorphous polymers such as ABS.

Stress-Strain Measurements

Stress-strain plots measured at different temperatures are useful tools for describing the thermal-mechanical behavior of plastic. Figures 3.7 through 3.13 illustrate tensile stress-strain plots at various temperatures for different grades of Celanex and Impet polyesters.

Also shown in Figures 3-7 through 3.13 are secant modulus-strain curves generated from the stress-strain curves for the same grades, again plotted versus temperature. These plots provide insight into mechanical performance at elevated temperatures and may be used in part design.

**** These sections contain general "rule-of-thumb" type information. This information should only be used for ballpark calculations, as a first approximation.***

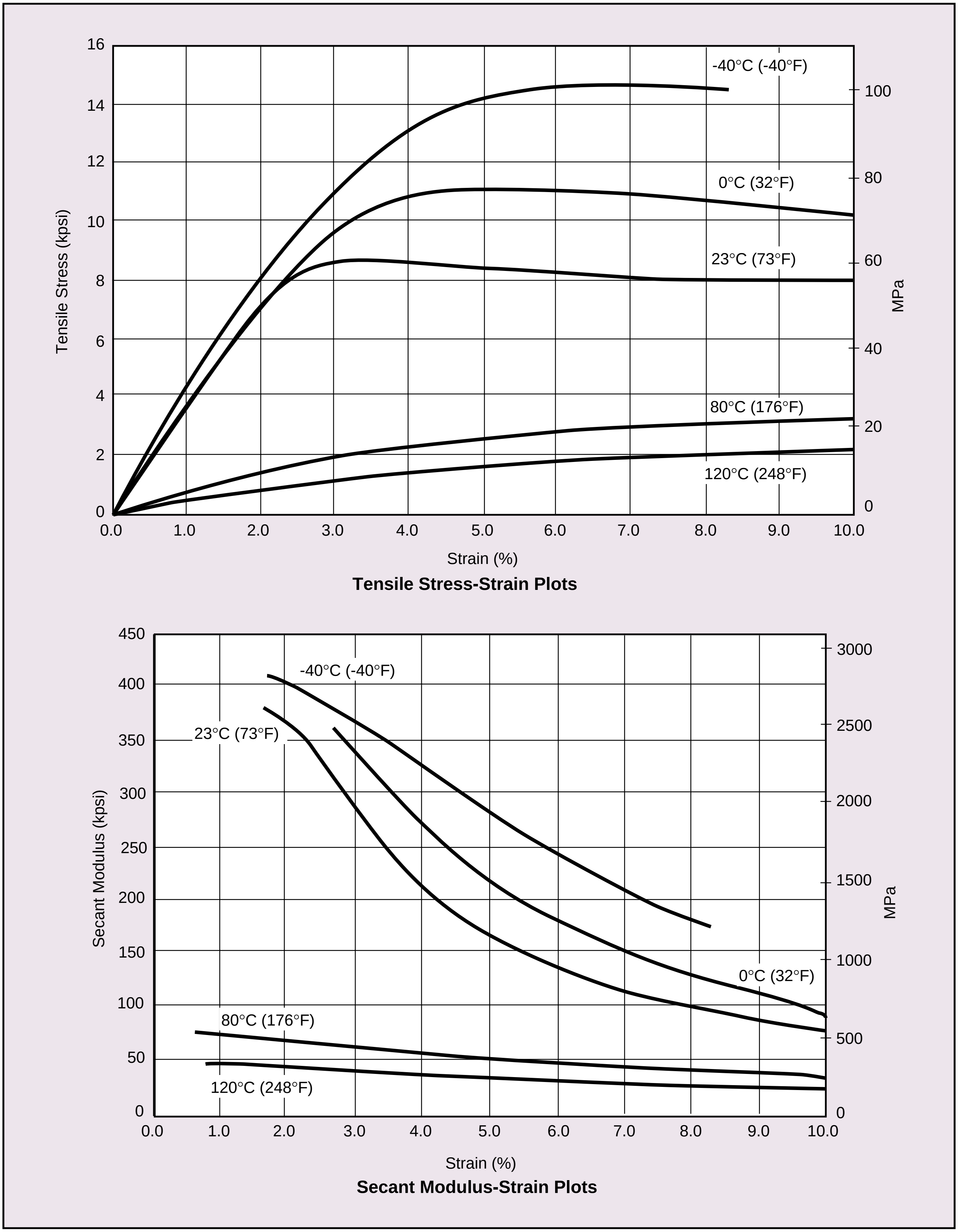


Figure 3.7 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for Unreinforced Celanex 2002.

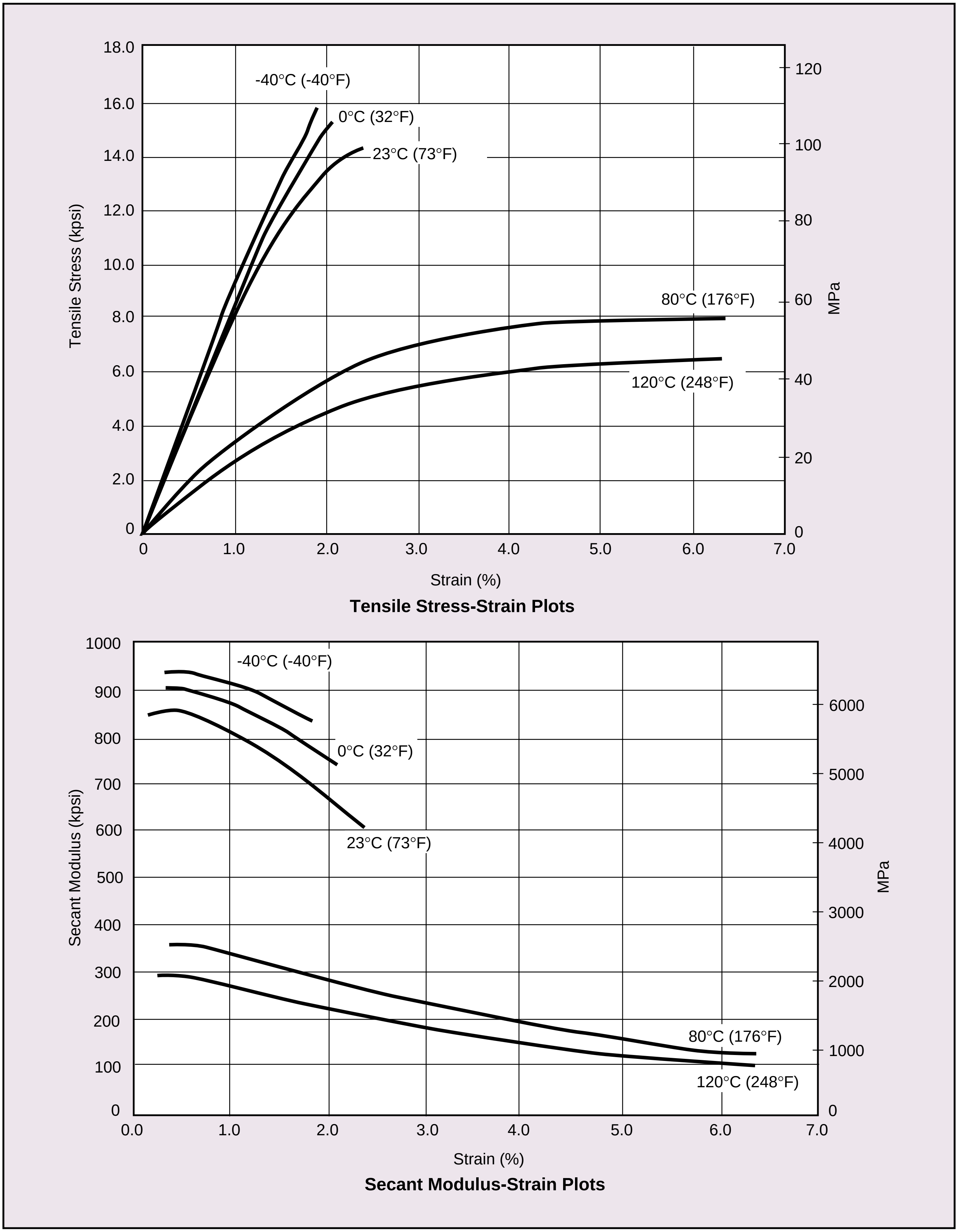


Figure 3.8 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for 15% Glass Reinforced Celanex 3200

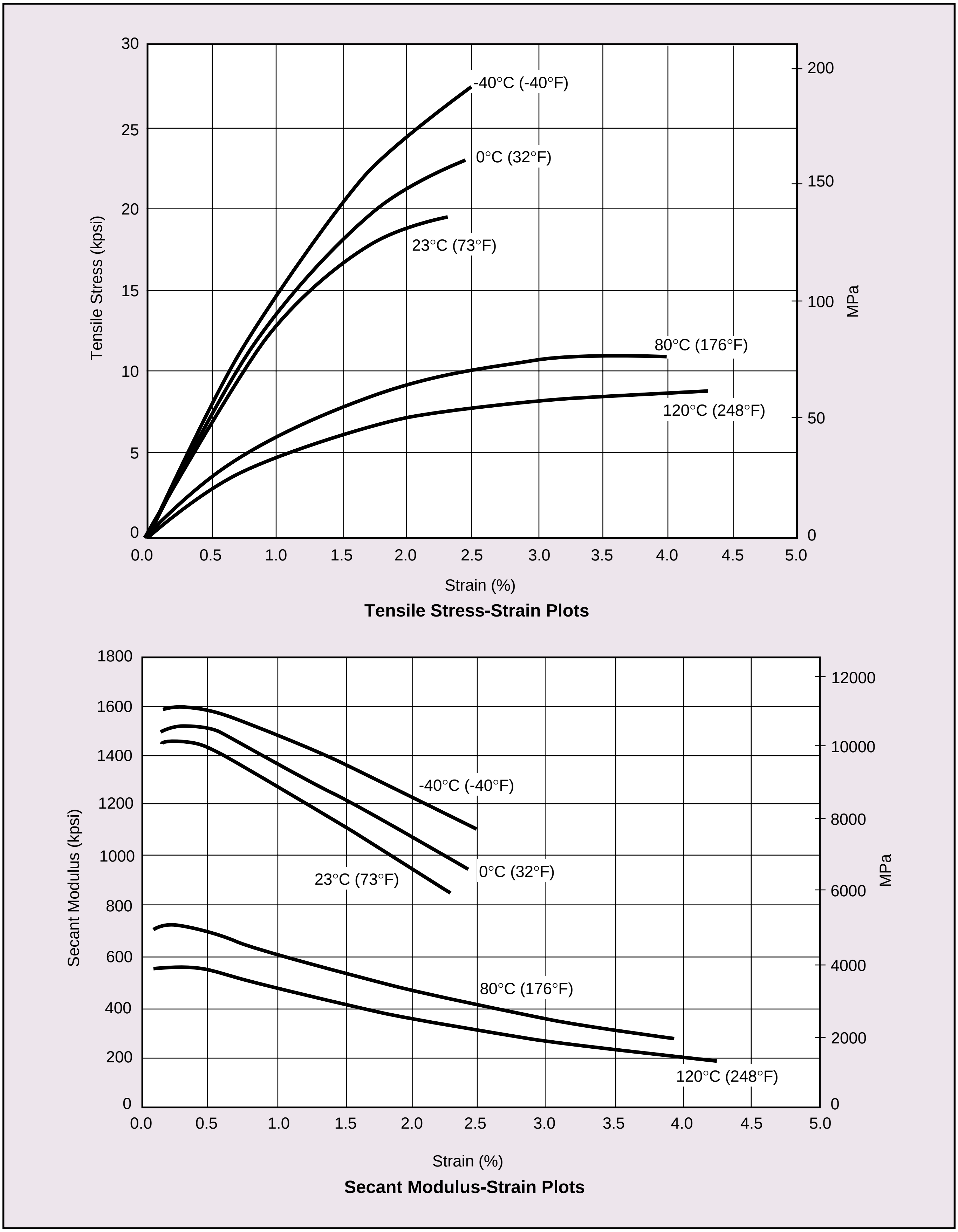


Figure 3.9 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for 30% Glass Reinforced Celanex 3300

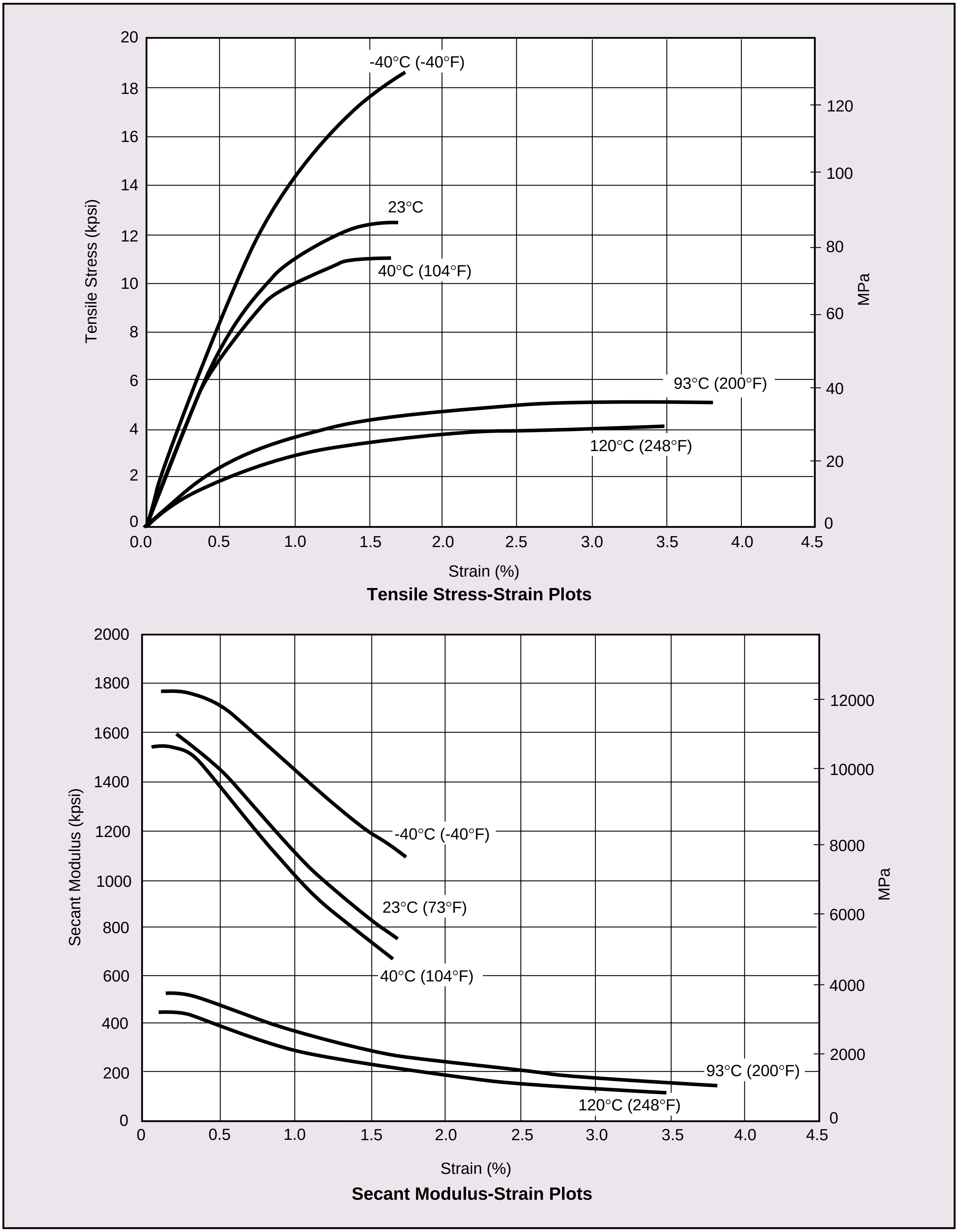


Figure 3.10 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Celanex J600

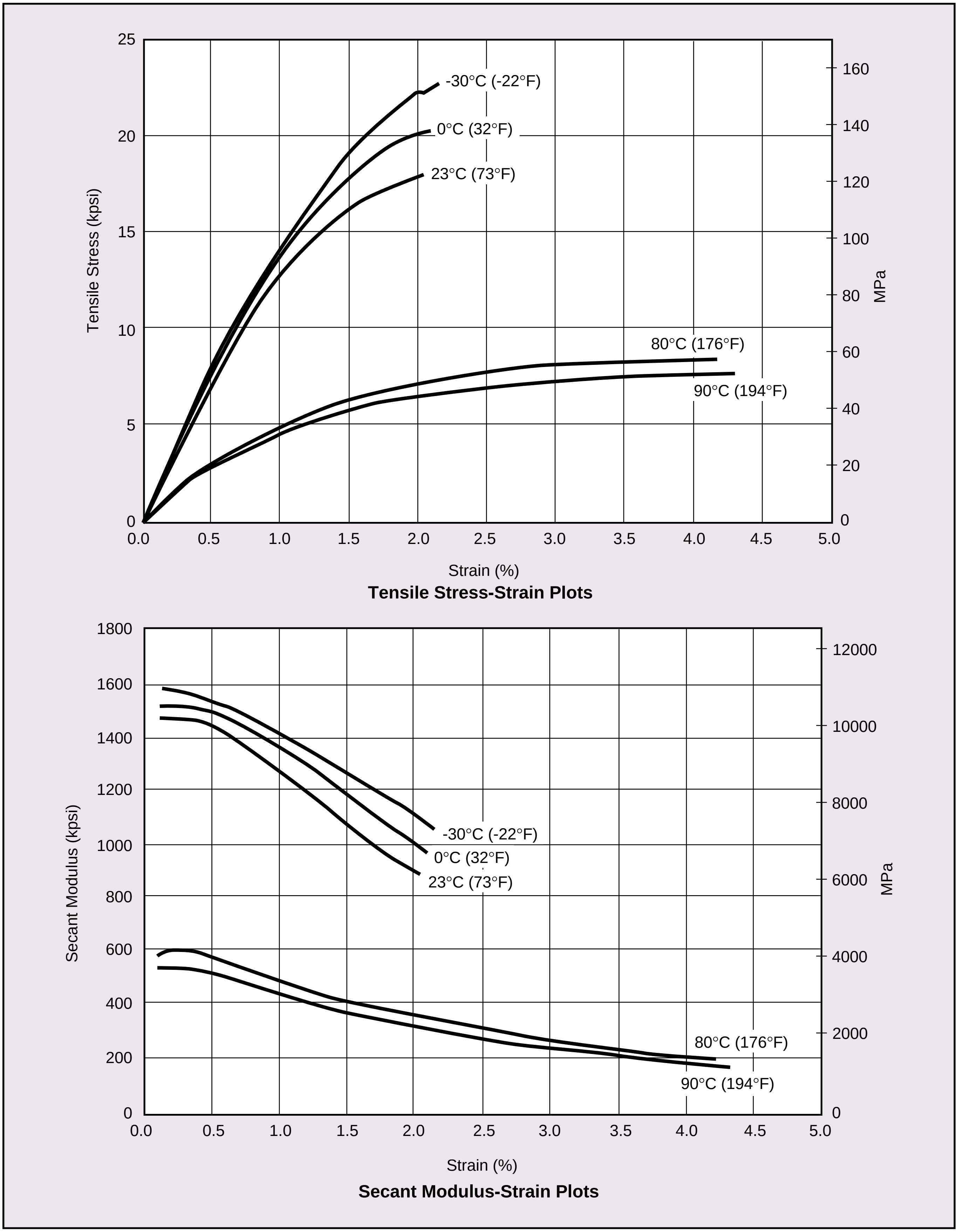


Figure 3.11 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Celanex 6500

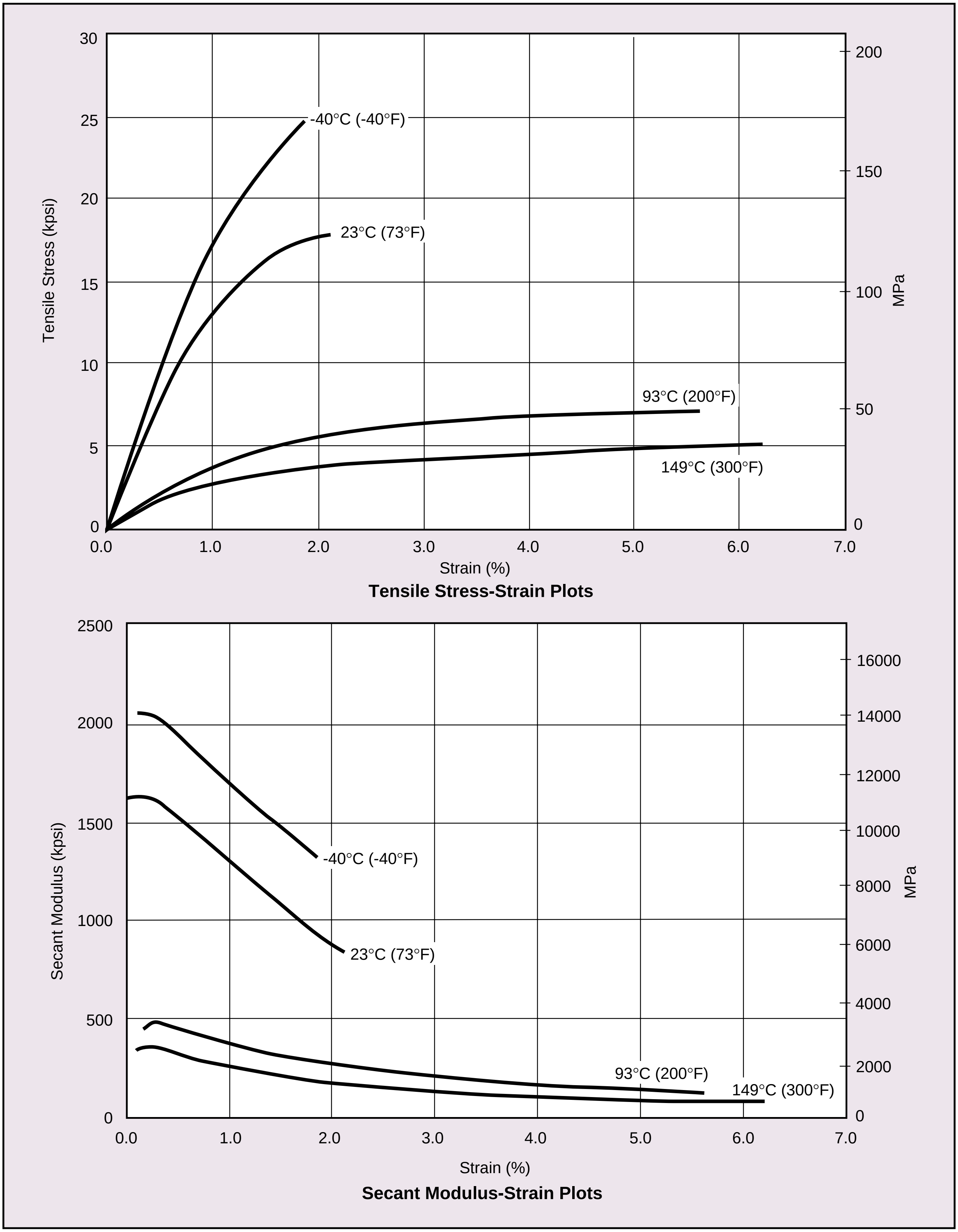


Figure 3.12 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Impet 830R

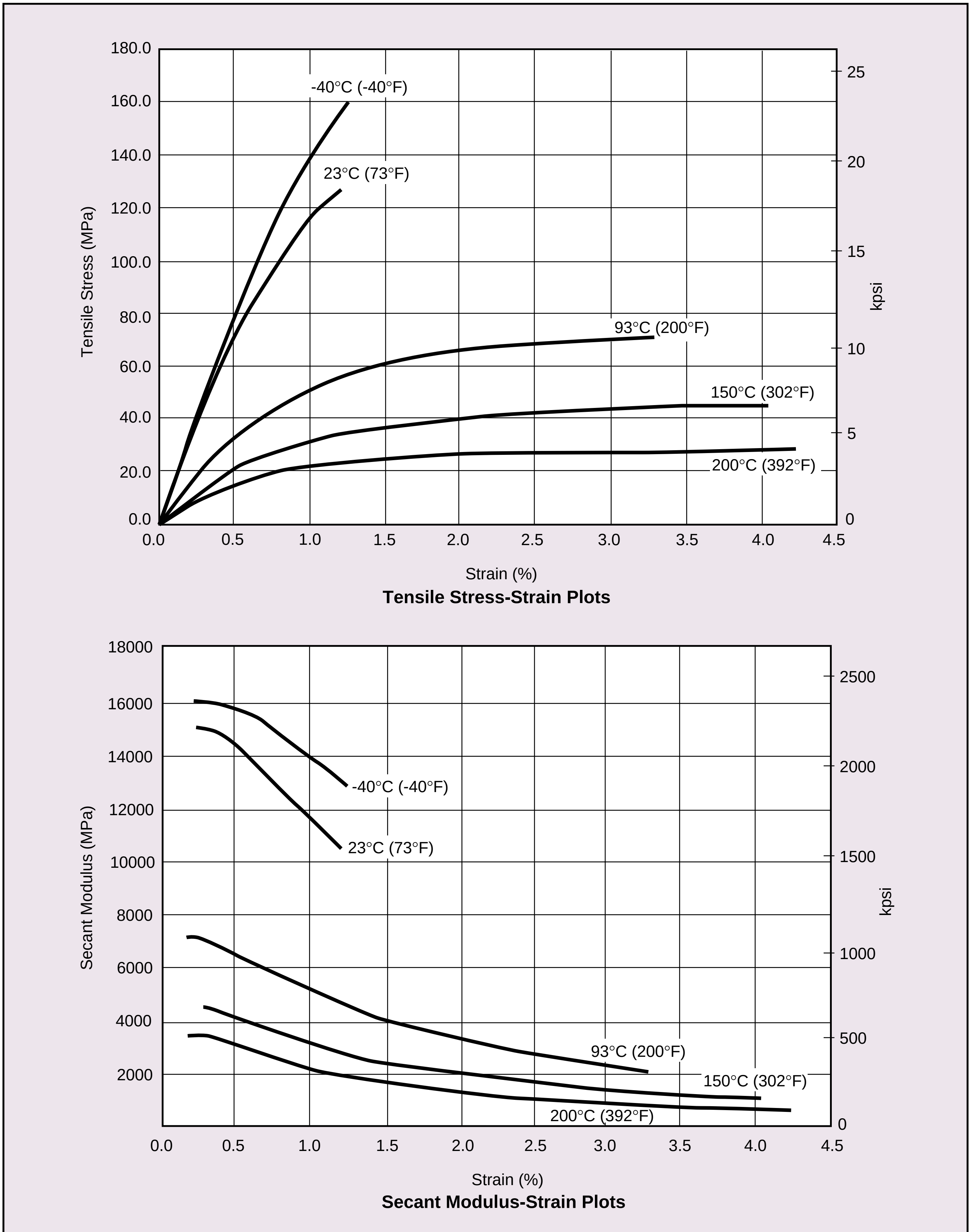


Figure 3.13 Typical Tensile Stress & Secant Modulus Plots at Different Temperatures for Glass/Mineral Reinforced Impet 840R

Influence of Elevated Temperature on Short Term Properties

Unlike many other engineering thermoplastic resins, Celanex and Vandar polyester resins will retain their outstanding mechanical performance properties at elevated temperatures. Heat deflection temperatures at 264 psi range from 54°C (131°F) for unreinforced Celanex grades to 209°C (408°F) for glass reinforced Celanex grades. As shown in Figures 3.14 to 3.21, Celanex resins retain significant levels of flexural strength and rigidity (flexural modulus) at elevated temperatures.

Figures 3.22 and 3.23 (page 3-22) show the retention of tensile and flexural properties for selected grades of Vandar Alloys.

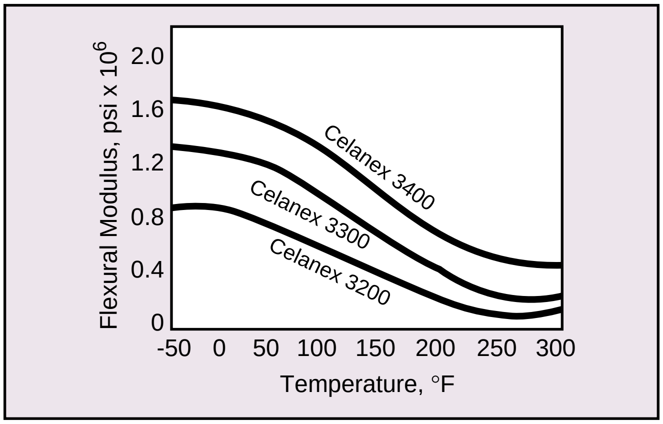


Figure 3.14 Flexural Modulus vs. Temperature for Glass Reinforced, General Purpose, Grades of Celanex® Thermoplastic Polyester

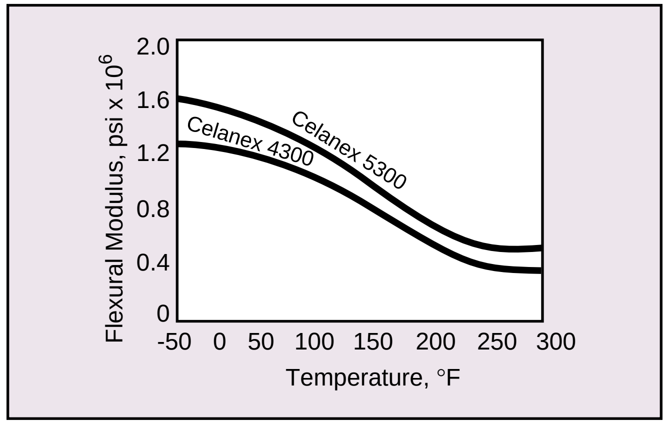


Figure 3.16 Flexural Modulus vs. Temperature for Glass Reinforced, Improved Impact/Surface Finish, Grades of Celanex® Thermoplastic Polyester

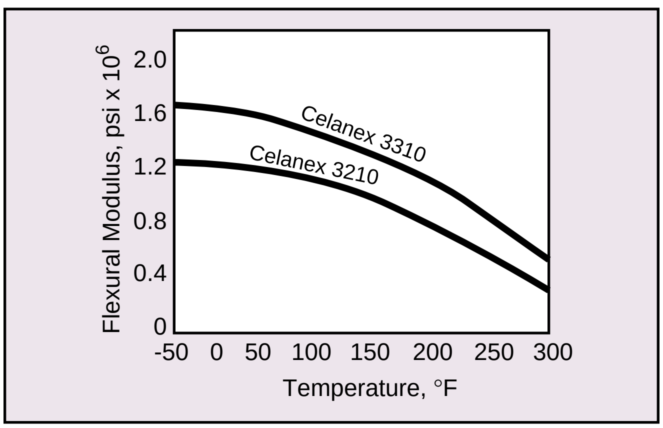


Figure 3.15 Flexural Modulus vs. Temperature for Glass Reinforced, Flame Retardant, Grades of Celanex® Thermoplastic Polyester

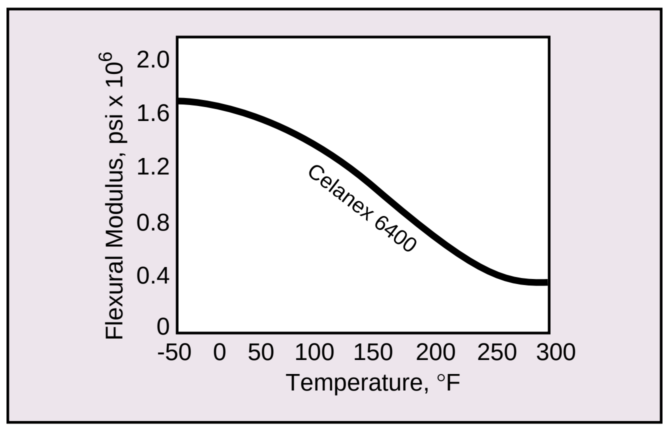


Figure 3.17 Flexural Modulus vs. Temperature for Glass Reinforced, Low Warp, Grade of Celanex® Thermoplastic Polyester

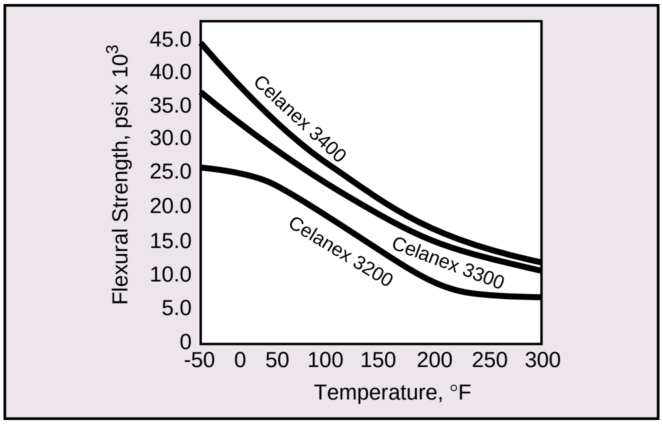


Figure 3.18 Flexural Strength vs. Temperature for Glass Reinforced, General Purpose, Grades of Celanex® Thermoplastic Polyester

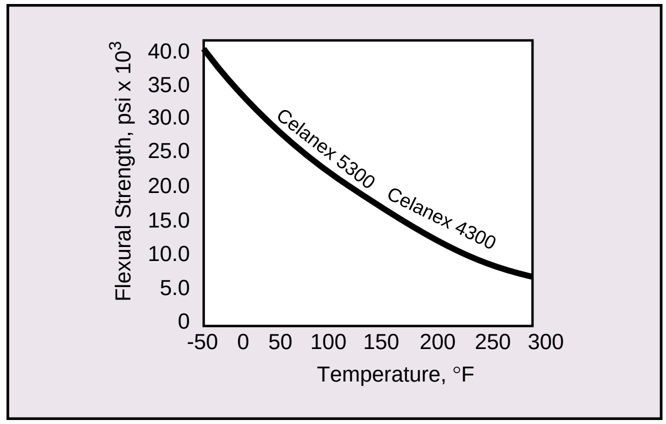


Figure 3.20 Flexural Strength vs. Temperature for Glass Reinforced, Improved Impact/Surface Finish, Grades of Celanex® Thermoplastic Polyester

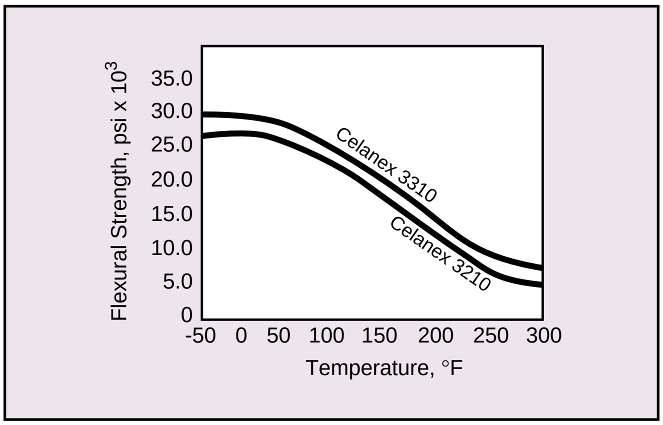


Figure 3.19 Flexural Strength vs. Temperature for Glass Reinforced, Flame Retardant, Grades of Celanex® Thermoplastic Polyester

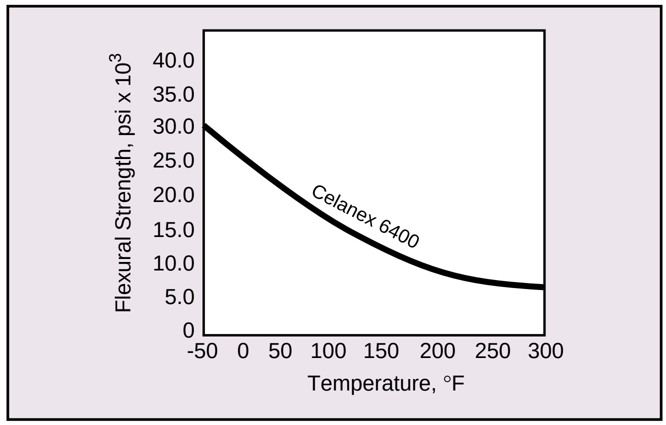


Figure 3.21 Flexural Strength vs. Temperature for Glass Reinforced, Low Warp, Grades of Celanex® Thermoplastic Polyester

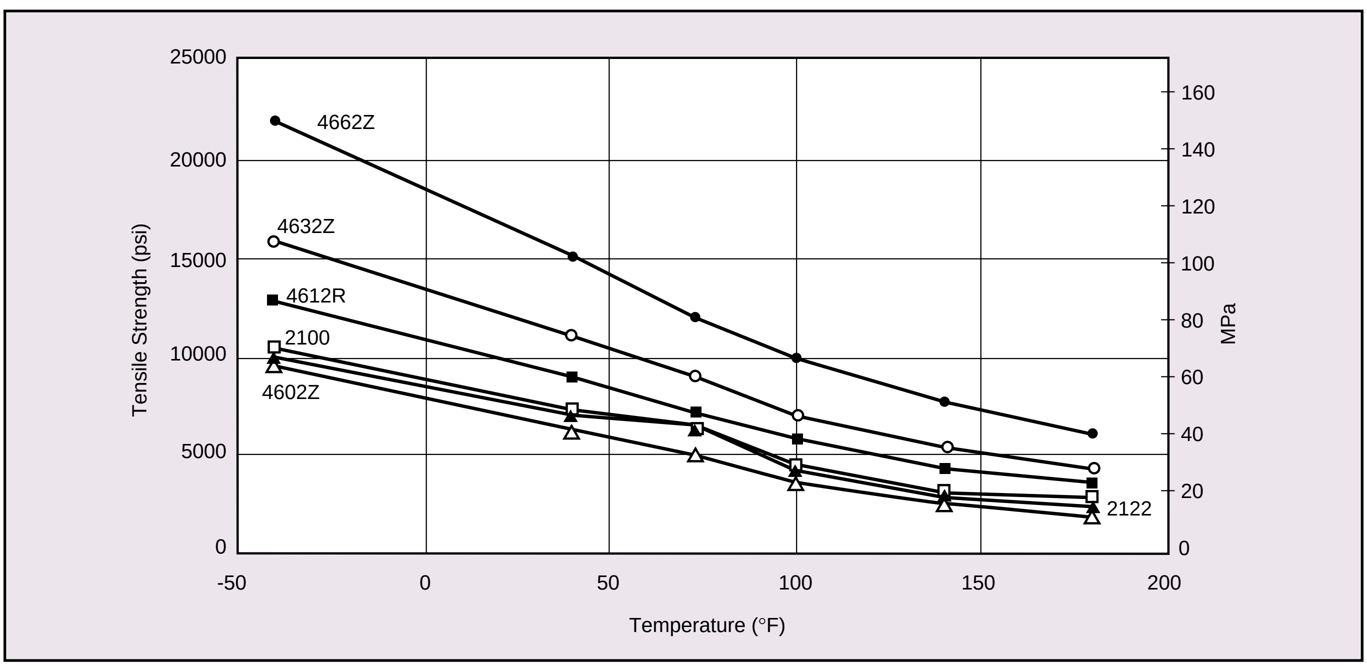
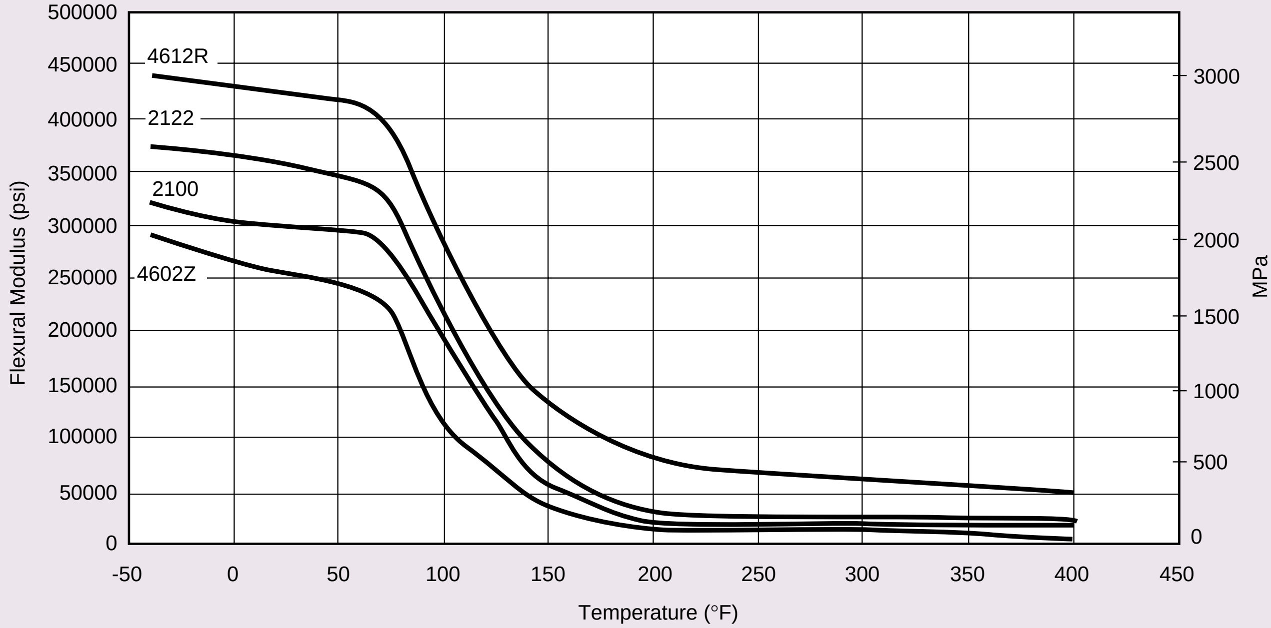
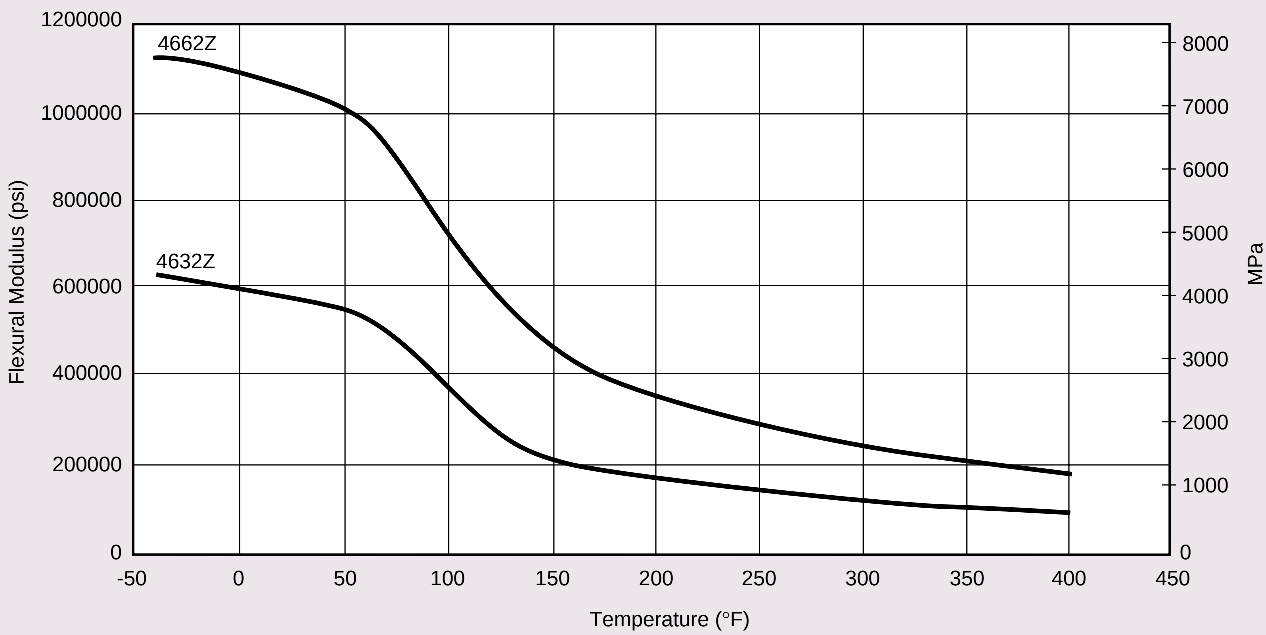


Figure 3.22 Tensile Strength vs. Temperature for Vandar® Thermoplastic Polyester Alloy



Lower Stiffness Grades of Vandar Polyester Alloy



Higher Stiffness Grades of Vandar Polyester Alloy

Figure 3.23 Flexural Modulus vs. Temperature for Various Grades of Vandar® Thermoplastic Polyester Alloy

Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) was developed primarily to investigate the morphology of materials together with their energy absorption characteristics. Parts designers have begun to use this technique to investigate elastic modulus behavior within their useful temperature range. The test is most useful when stress-strain curves are lacking or incomplete over the operating temperature range of the material.

Test samples can be loaded in tension, bending or shear. The test imposes very small oscillating deflections while measuring the resulting force on the test specimen over a temperature range of -40°C to almost the melting point of the material. A continuous plot is generated of modulus (or other characteristic) versus temperature.

The modulus versus temperature plot is often normalized by dividing all the modulus data per individual curve by the room temperature modulus value to more readily compare different DMA tests obtained on the same material but run under different test conditions.

A semi-log plot of modulus versus temperature provides additional insight into modulus values at elevated temperature. The beginning of the final downward curvature at elevated temperature is often considered the maximum useful temperature of the material.

Note: Designers should exercise extreme care and evaluate prototype parts whenever operating specifications call for thermal exposure close to the material's DMA downward point of curvature.

Figure 3.24 illustrates the normalized DMA plot of flex modulus versus temperature of typical PBT grades. Most grades will fall within the range of these plots.

Designers can use the DMA plot to determine a shift factor to be applied to the room temperature modulus value to obtain a modulus at any operating temperature. For example, the modulus of a standard unfilled PBT is 20% of its room temperature value at approximately 110°C.

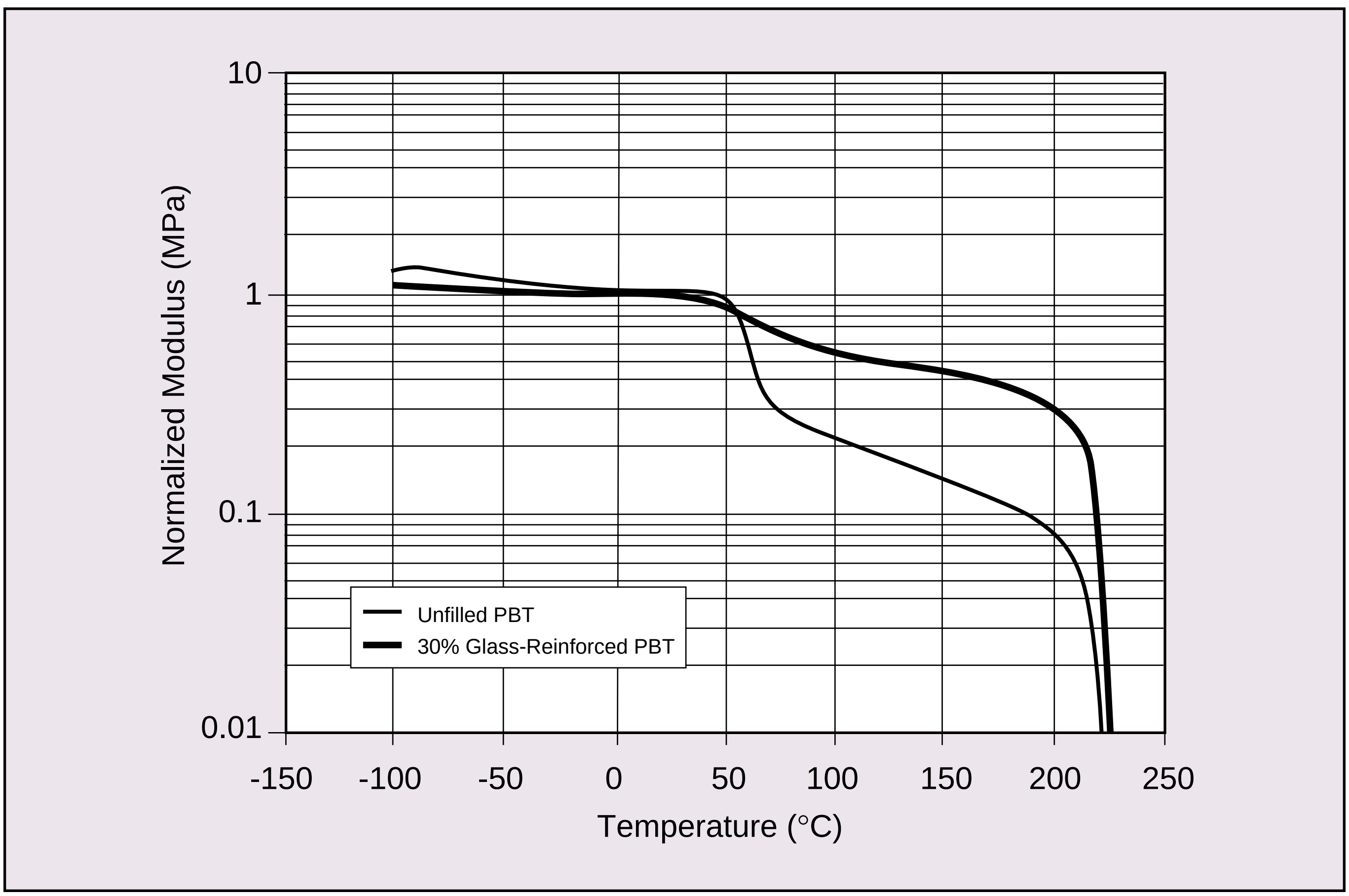


Figure 3.24 Typical Normalized DMA for Celanex® PBT

Deflection Temperature Under Load

Deflection Temperature Under Load (DTUL) is useful for comparing different materials for their relative resistance to mechanical stress (three-point bending) at elevated temperature. Figure 3.25 illustrates DTUL values (using ISO Test Method 75) for various subcategories of unreinforced and reinforced polyesters.

Designers can, however, obtain much more information than just the relative resistance information referred to above by properly interpreting the DTUL test results.

Under DTUL, a test specimen is loaded in three-point bending at a specified stress. Using a heating medium (such as an oil bath), the deflection is then continuously measured as the temperature of the test bar is increased at a rate of 2°C per minute. The temperature is recorded when a specific deflection is reached. Since both the stress and strain (deflection) are specified, if it is assumed that the material is linearly elastic and follows Hooke's Law; then the test temperature reported corresponds to a specific value of the flexural modulus.

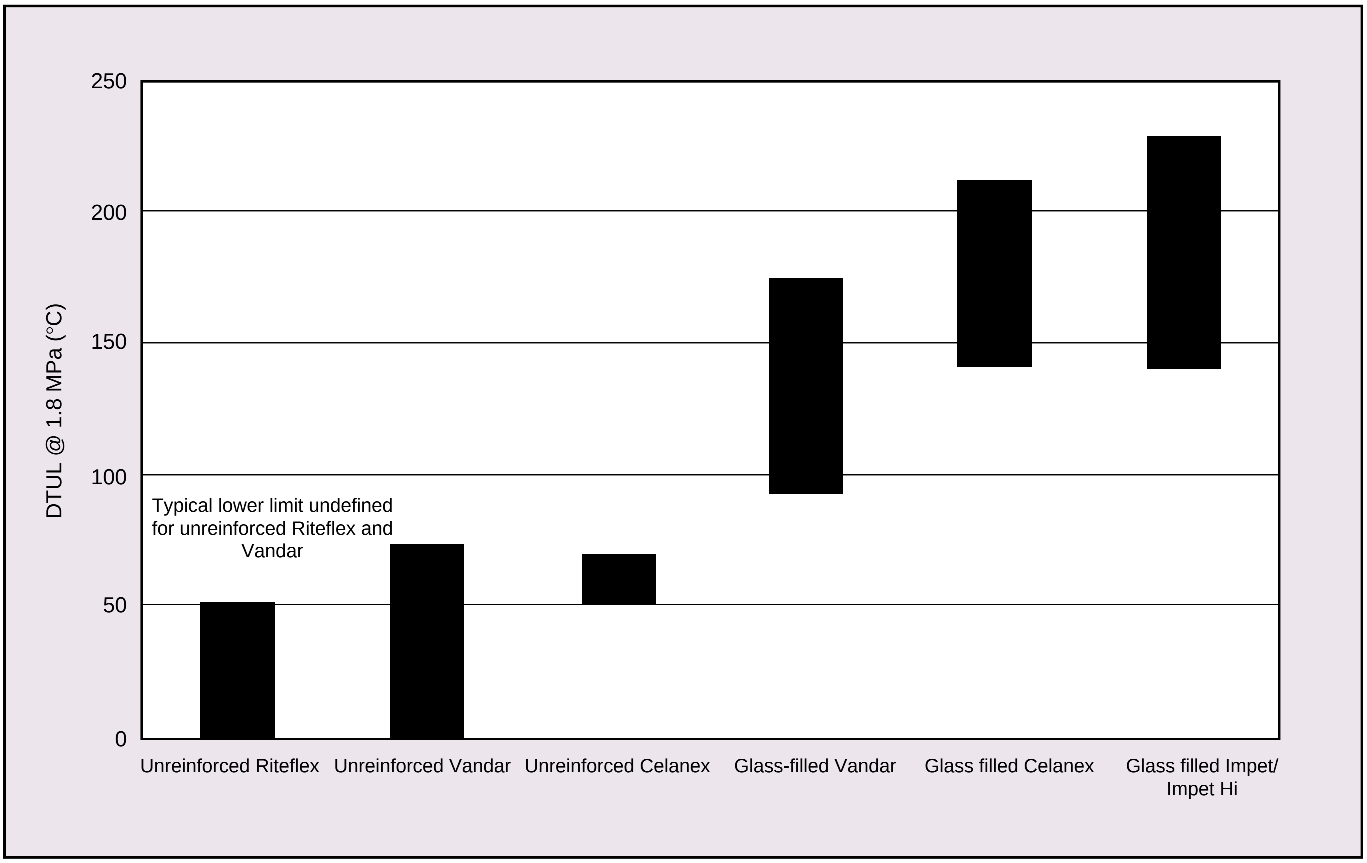


Figure 3.25 Typical DTUL Range for Various Subcategories of Polyester Resins

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 Figures 3.26 and 3.27.

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.

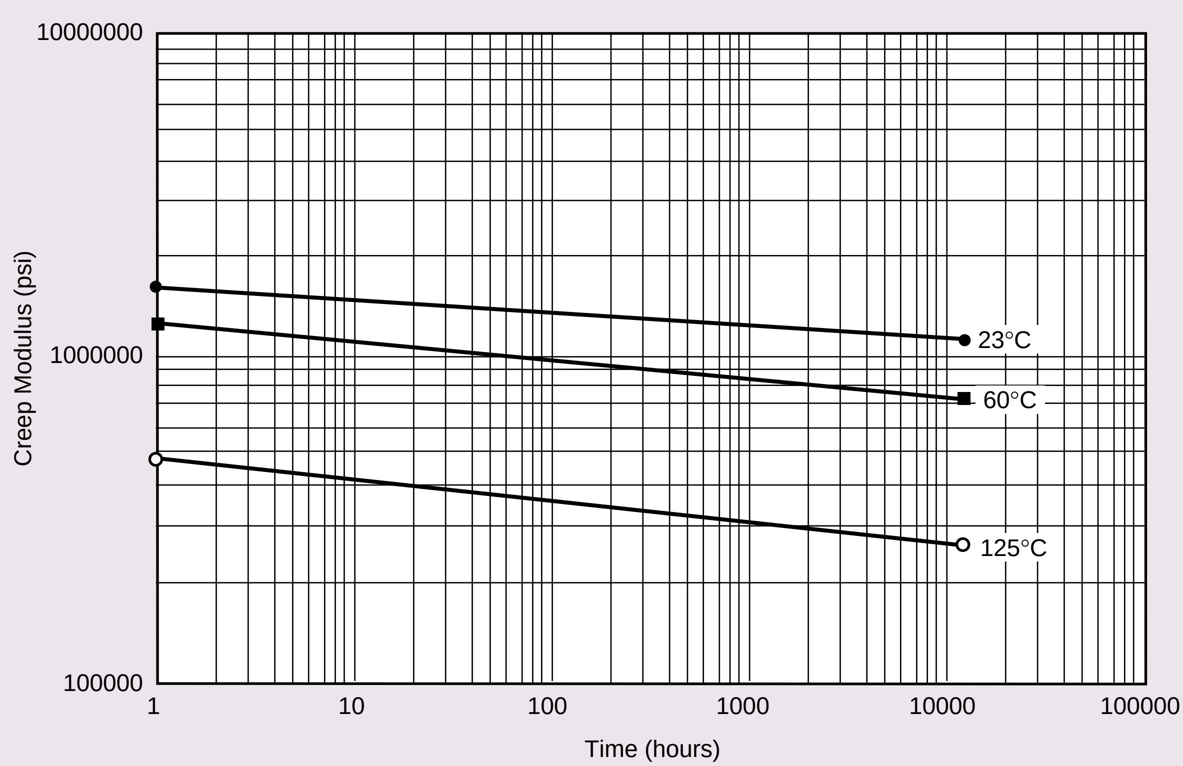


Figure 3.26 Flexural Creep Modulus for Glass/Mineral Reinforced Impet 330R at 4,000 psi

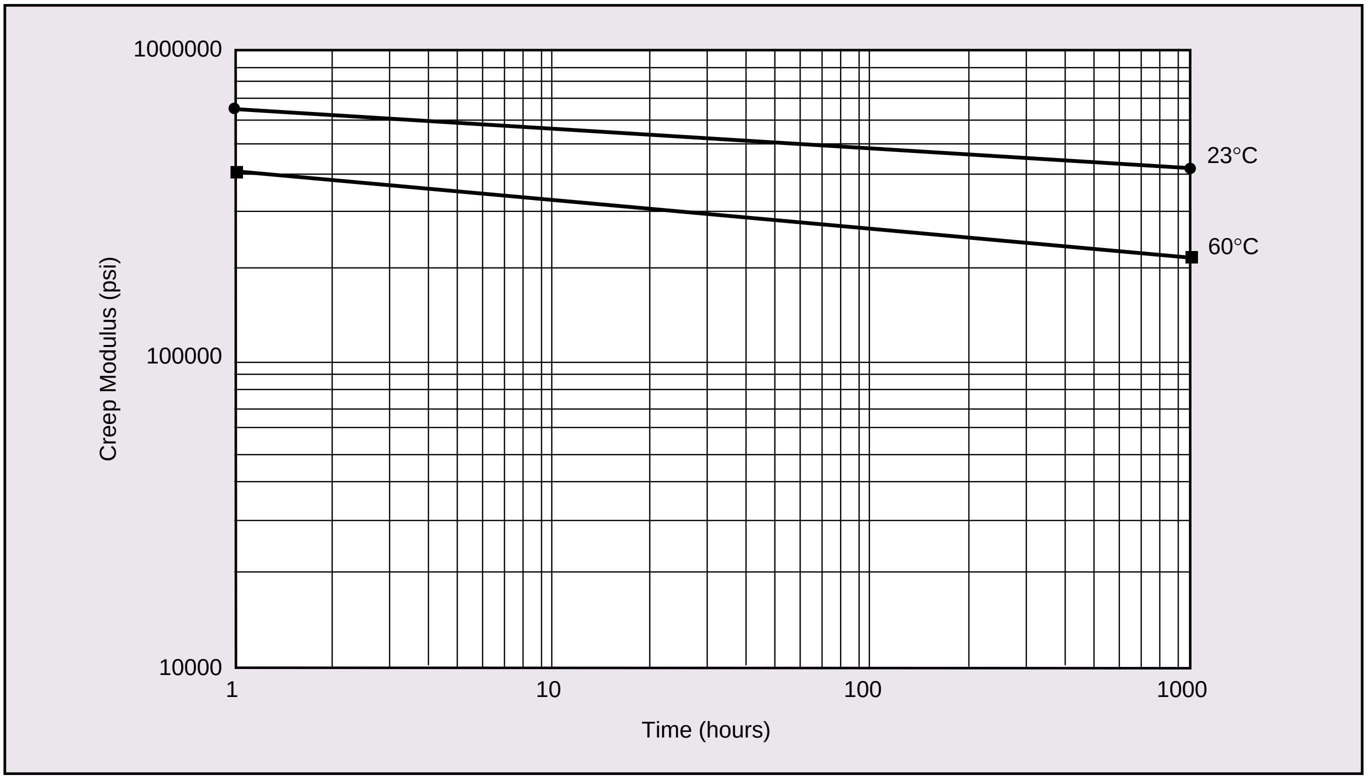


Figure 3.27 Flexural Creep Modulus for Glass/Mineral Reinforced Impet 610R at 2,000 psi

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 3.28 shows creep results when tested by ASTM methods which call for 24 hour conditioning at test temperatures before applying the load. Figures 3.29 through 3.32 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 increases. 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.

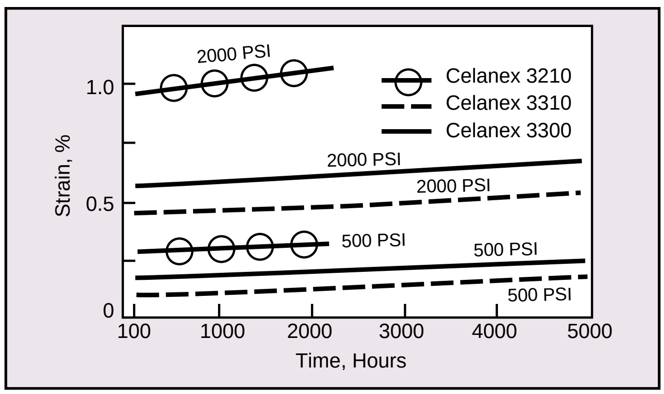


Figure 3.28 Flexural Creep at 105°C for Glass Reinforced Celanex 3210, 3310 and 3300

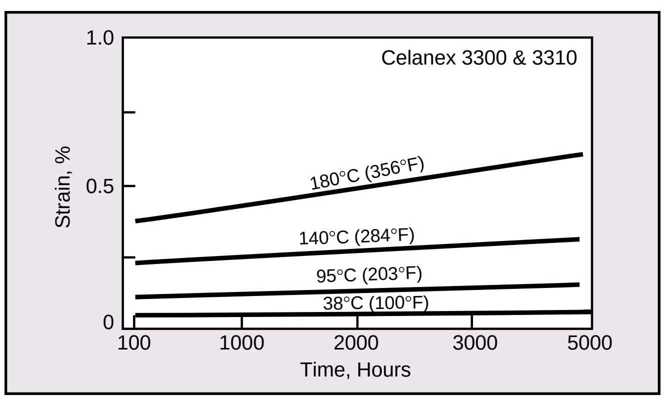


Figure 3.29 Flexural Creep at 500 psi Maximum Stress for Glass Reinforced Celanex 3300 and 3310

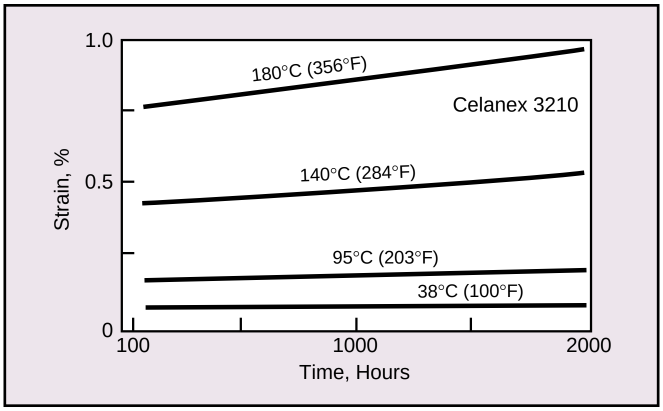


Figure 3.30 Flexural Creep at 500 psi Maximum Stress for Glass Reinforced Celanex 3210

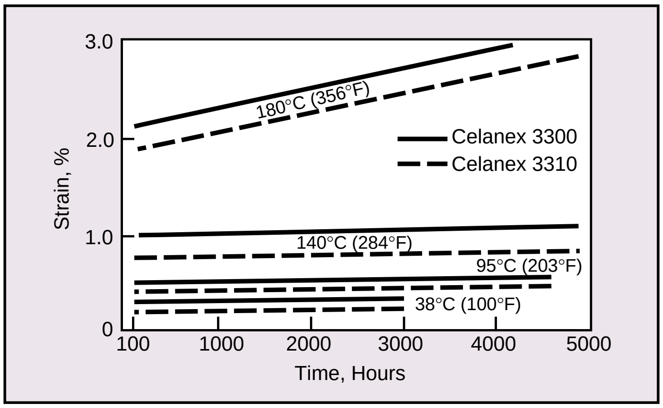


Figure 3.31 Flexural Creep at 2000 psi Maximum Stress for Glass Reinforced Celanex 3300 and 3310

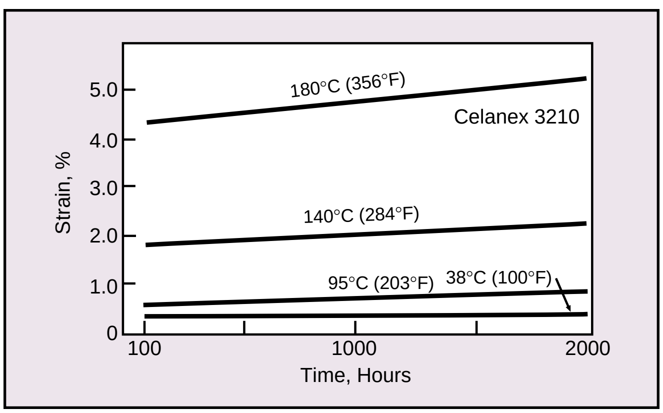


Figure 3.32 Flexural Creep at 2000 psi Maximum Stress for Glass Reinforced Celanex 3210

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.

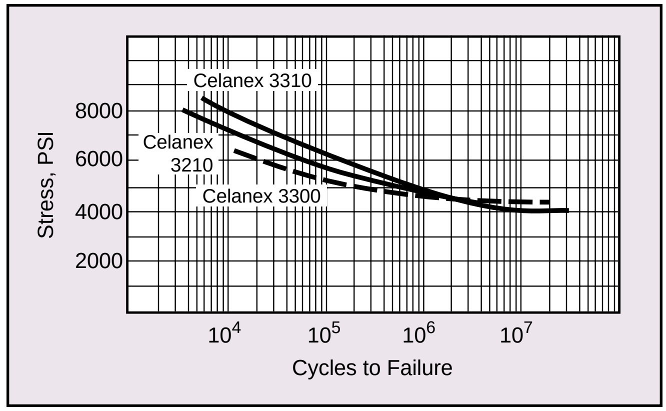


Figure 3.33 Flexural Fatigue Plot for Various Glass Reinforced Grades of Celanex® Thermoplastic Polyester

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

Figure 3.33 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 end-use environment, may overestimate the fatigue performance of the part by failing to consider aging effects at elevated temperature.

Dimensional Stability

Coefficient of Linear Thermal Expansion

The coefficient of linear thermal expansion (CLTE) is a measure of the linear change in dimensions with changes in temperature. Tables 4.1 through 4.4 show CLTE values in SI units for various grades of Celanex®, Impet®, Vandar®, and Riteflex® thermoplastic polyesters. To convert SI units to equivalent English units, divide mm/mm/°C by 1.80 to obtain in/in/°F.

Table 4.1 CLTE Values for Grades of Celanex® Thermoplastic Polyester

Grade	Temperature Range °C	Measured Direction	mm/mm/°C x 10^{-5}
J600	23 to 80	Flow	2.5
1600A	23 to 80	Flow	11
2000	23 to 80	Flow	11
2002	23 to 80	Flow	11
2004-2	23 to 80	Flow	10
2012-2	23 to 80	Flow	11
2016	23 to 80	Flow	11
3200	23 to 80	Flow	4.0
3210-2	23 to 80	Flow	3.5
3226	23 to 80	Flow	3.5
3300	23 to 80	Flow	2.5
3310-2	23 to 80	Flow	2.5
3316	23 to 80	Flow	2.5
3400	-40 to 50	Flow	0.9
4016	23 to 80	Flow	10
4300	23 to 80	Flow	2.5
4305	23 to 80	Flow	2.0
4306	23 to 80	Flow	2.0
5300-2	23 to 80	Flow	2.0
6400-2	23 to 80	Flow	2.5
6500	23 to 80	Flow	2.8
7316	23 to 80	Flow	3.0

Table 4.2 CLTE Values for Grades of Impet® Thermoplastic Polyester

Grade	Temperature Range °C	Measured Direction	mm/mm/°C x 10^{-5}
320R	-30 to 50	Flow	3.4
		Transverse	7.6
	50 to 80	Flow	2.7
		Transverse	7.6
	80 to 160	Flow	1.51
		Transverse	4.7
330R	-30 to 50	Flow	3.2
		Transverse	7.7
	50 to 80	Flow	2.7
		Transverse	1.01
	80 to 160	Flow	2.2
		Transverse	8.3
340R	-30 to 50	Flow	6.8
		Transverse	6.5
	50 to 80	Flow	1.03
		Transverse	8.5
	80 to 160	Flow	1.04
		Transverse	10.4
610R	-30 to 50	Flow	3.8
		Transverse	5.9
	50 to 80	Flow	3.8
		Transverse	8.5
	80 to 160	Flow	2.3
		Transverse	8.5
630R	-30 to 50	Flow	3.1
		Transverse	5.0
	50 to 80	Flow	2.9
		Transverse	6.3
	80 to 160	Flow	1.3
		Transverse	6.7
740	-30 to 50	Flow	3.1
		Transverse	10.3
830R	-30 to 50	Flow	3.1
		Transverse	7.2
	50 to 80	Flow	2.0
		Transverse	11.0
	80 to 160	Flow	1.42
		Transverse	10.4
840R	-30 to 50	Flow	3.1
		Transverse	10.3

Table 4.3 CLTE Values for Grades of Vandar® Thermoplastic Polyester Alloy

Grade	Temperature Range °C	Measured Direction	mm/mm/°C x 10^{-5}
2100	23 to 80	Flow	13
4361	23 to 80	Flow	1.1
		Transverse	11.2
4602Z	23 to 80	Flow	13
4612R	23 to 80	Flow	4.0
4632Z	23 to 80	Flow	2.5
4662Z	23 to 80	Flow	1.5
6000	23 to 80	Flow	8.6
		Transverse	8.1
8000	23 to 80	Flow	13
8929	23 to 80	Flow	12.8
		Transverse	8.8
9114	23 to 80	Flow	10.0
		Transverse	11.0
9116	23 to 80	Flow	6.1
		Transverse	9.2

Mold Shrinkage During Processing

Unreinforced polyester resins shrink uniformly in both material flow and transverse directions. For reinforced polyester resins, shrinkage in the direction of material flow is always less than in the transverse direction.

Variables that significantly affect part shrinkage during injection molding include:

- Melt/mold temperatures.
- Injection pressure.
- Flow direction, gate/runner design and size.
- Part or wall thickness and size.
- Presence (low shrinkage) or absence (high shrinkage) of fibrous reinforcements.

More information on mold shrinkage is provided in Chapter 8. Also, for recommended molding conditions, refer to the publication titled “Celanex®, Vandar®, Impet® and Riteflex® Thermoplastic Polyesters - Processing and Troubleshooting Guide (PE-6).”

Warpage

Poor part and mold design, improper molding conditions, or any combination of these can contribute to warpage problems in thermoplastic polyester materials. For more information on this subject, refer to Chapter 7.

Table 4.4 CLTE Values for Grades of Riteflex® Thermoplastic Polyester Elastomer

Grade	Temperature Range °C	Measured Direction	mm/mm/°C x 10^{-5}
635	23 to 80	Flow	22
640	23 to 80	Flow	22
647	23 to 80	Flow	20
655	23 to 80	Flow	20
663	23 to 80	Flow	18
677	23 to 80	Flow	14

Annealing

The main purpose of annealing is to stabilize part dimensions by accelerating the effects of stress relaxation. The decision to anneal polyester parts should be made during the planning stage and definitely before machining the mold cavity and core to size.

Few applications require annealing. Parts made from polyester resin which are properly designed and molded in a hot, 93 - 121°C (200 - 250°F) mold have sufficient dimensional stability for all but the most exacting requirements. This is particularly true when the mold temperature is hotter than end-use temperature.

However, if resin parts are to be used at higher temperature (over 93°C or 200°F), and dimensional stability is required, then annealing is recommended. Annealing relieves residual stresses in moldings, causing most “stress relaxation” shrinkage to occur in the annealing operation rather than in service. Annealing can also increase crystallinity.

Caution: In some cases, stress relief through annealing can lead to part warpage, especially if shrinkage is non-uniform. Multiple test parts should be produced initially to determine if this problem arises.

Polyester resin parts may be annealed in an air circulating oven capable of maintaining uniform temperature throughout its interior. Recommended annealing temperature is 204±2.8°C (400 ±5°F).

Annealing time depends primarily on part thickness, part geometry, and processing conditions. It is good practice to determine minimum annealing time and then add a “safety factor”. This can be done by placing several parts in the oven and removing them one at a time at predetermined intervals. After a cooling time of at least 24 hours, the parts are measured, and the point at which the dimensions show no further change is the minimum annealing time.

A “rule of thumb” on annealing time for most polyester resin parts is one to three hours in air, depending on part thickness. It is suggested that the minimum annealing time be determined for a particular part as described above.

Typical shrinkage encountered in glass fiber reinforced grades during annealing is up to 0.002 inch/inch in the flow direction and 0.003 inch/inch in the transverse direction. This is in addition to the mold shrinkage data shown in Tables 8.3 through 8.6, Chapter 8.

Moisture Absorption

Unlike other engineering thermoplastics, Celanex, Vandar, Impet, and Riteflex polyesters are not as sensitive to dimensional change due to moisture absorption. Their mechanical and thermal properties are virtually unaffected when exposed to moist environments at room temperature. See Table 5.1 for dimensional change after exposure to tap water. The softer grades of Riteflex polyesters and Vandar polyesters absorb somewhat more water than PBT or PET, but still have relatively low moisture absorption or dimensional change. See CX-4, IP-4, VN-4 and RF-4 brochures for moisture absorption values.

Environmental Resistance

Introduction

Before selecting a particular material for use in a part, designers must consider the end-use environment (especially chemical, thermal, and weathering parameters) that the part will be exposed to during its service life. In addition, processing, assembly, finishing, and cleaning operations sometimes have adverse effects on part performance especially if harsh solvents or high stress loads are encountered during assembly.

This chapter discusses the resistance of Celanex®, Vandar®, Impet®, and Riteflex® polyesters to various environments.

Celanex® Thermoplastic Polyesters

Chemical Resistance

Being a crystalline polymer, Celanex polyesters has excellent resistance to stress cracking in various chemical environments. These include dilute acids, bases and salt solutions, most organic chemicals and automotive chemicals and ozone.

Celanex polyesters are also resistant to fungus growth and are suitable for soil burial. They are noncorrosive to metals.

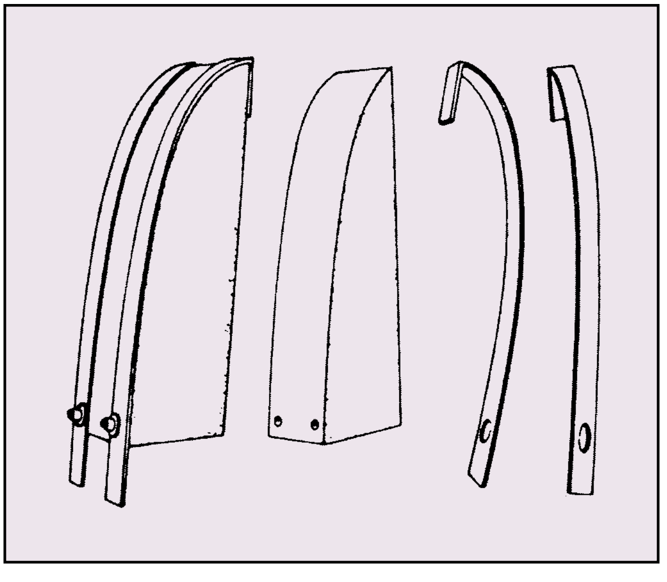


Figure 5.1 Jig for Stress Cracking Test on Celanex 3300

Stress Cracking

In a stress cracking test, Celanex 3300 strips 25.4 mm (1 in.) wide by 0.8 mm (.030 in.) thick were placed with metal bands on bending jigs having varying radius of curvature (see Figure 5.1).

The jigs were immersed in the following solvents at the different temperatures shown:

- Fuel C (50% toluene + 50% iso-octane) at 60°C
- Ethylene Glycol at 93°C
- Transmission Fluid A at 93°C
- Heavy Duty, Lockheed Brake Fluid at 60°C
- Uniflo Oil at 93°C.
- BTX (50% Benzene, 37.5% Toluene, 12.5% Xylene) at 23°C
- Skydrol at 23°C

After 5 hours immersion at a stress level of 82.8 MPa (12000 psi), no evidence of stress cracking was observed via a 30 power microscope.

Prior experience with noncrystalline (amorphous) resins known to stress crack (i.e. polycarbonate, polymethylmethacrylate, polystyrene, etc.) indicates that stress crack failures generally occur within one hour of immersion. Degreasing of soldered Celanex electrical components can be accomplished using standard organic solvents without stress cracking.

Long Term Chemical Resistance

Long term chemical resistance data, based on the total immersion of laboratory specimens, are shown in Table 5.1. The chemical resistance of glass reinforced Celanex polyester, categorized by type of exposure media, are summarized in the following paragraphs:

Acids - Celanex polyester experiences only minor changes in tensile strength and dimensions in the acids tested at room temperature. Prolonged exposure at elevated temperatures will result in gradual polymer deterioration.

Bases - Celanex polyester can withstand room temperature exposure to weak bases (pH 10 or lower). However, strong bases will degrade Celanex 3300 at room temperature within a period of weeks. Chemical attack at elevated temperatures will occur much more rapidly. Where Celanex polyester is considered for applications in contact with bases, thorough testing is suggested.

Water - Celanex polyester has good, long term resistance to attack by water at room temperature and up to 52°C (125°F). For prolonged exposure in hot water, Celcon acetal copolymer, rather than Celanex polyester, should be considered.

Celanex polyester can withstand short term exposure to steam and pressurized water as high as 149°C (300°F). Hot aqueous solutions will attack Celanex polyester upon prolonged exposure.

Organic Chemicals - Celanex polyester has excellent resistance to most organic solvents and chemicals at room temperature, with small changes in strength and dimensions being observed after prolonged exposure. At elevated temperatures, however, some changes in properties may occur. In many cases, the change may be due to absorption of the particular organic chemical resulting in a reduction of strength due to plasticization - rather than true chemical attack. Where Celanex polyester is considered for prolonged contact with organic chemicals at higher temperatures, thorough testing of prototypes should be done to insure satisfactory part performance.

Selected tests show that Celanex polyester is essentially unaffected by the following materials at 23°C (73°F):

- Freon 160, 170 and 180
- Trichloroethylene
- Ethyl Acetate
- Oils & Fats
- Methyl Ethyl Ketone

Automotive Chemicals - Celanex has excellent long term resistance to gasoline at temperatures up to 60°C. Other automotive chemicals such as transmission and brake fluids, motor oil, and lubricating grease (as shown in Table 5.1) will gradually deteriorate Celanex polyester upon continuous, complete immersion at elevated temperatures.

However, exposure to occasional splashing or vapors of these chemicals will not normally degrade Celanex polyester. See Table 5.2 (page 5-6) for test results in ethylene glycol.

Table 5.1 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

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

Table 5.1 Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters (Continued)

Material	Time (Days)	Temperature °C (°F)	% Change Tensile Strength	Weight	Diameter*
Acids, Bases and Dilute Salt Solutions (Continued)					
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
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

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

Table 5.1 Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters (Continued)

Material	Time (Days)	Temperature °C (°F)	% Change Tensile Strength	% Change Weight	% Change Diameter*
Organic Chemicals (Continued)					
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
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 (10-20-40)	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

** 1/8” thick x 2” diameter disc.*

Table 5.1 Chemical Resistance of Glass Reinforced Celanex® Thermoplastic Polyesters (Continued)

Material	Time (Days)	Temperature °C (°F)	% Change Tensile Strength	% Change Weight	% Change Diameter*
Automotive Chemicals (Continued)					
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	1 -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
Houton-Cosmo Lubric 2425	180	23 (73)	+1.0	0.0	0.0
	360	23 (73)	-16.7	—	0.0

** 1/8” thick x 2” diameter disc.*

Table 5.2 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). Exposed 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

Ozone Resistance - Parts utilized in electrical applications are sometimes exposed to an ozone environment. Tests conducted on Celanex 3300 show that it retained 70% of its original tensile impact strength after 50 hours exposure to a 1.7% ozone concentration at 121°C (250°F). On this basis, Celanex polyester has good resistance to ozone.

The results of a series of tests comparing the chemical resistance of Celanex thermoplastic polyester with other engineering plastics are shown in Table 5.3.

Table 5.3 Chemical Resistance of Celanex® Thermoplastic Polyester Vs. Other Engineering Resins at 23°C (73°F)

Material	Acetal Copolymer	Acetal Homo-polymer	Styrene Modi-fied PPO	Polycarbonate	GP & HS Nylon 66	Thermoplastic Polyester
Acetic Acid 5%	G	F	G	G	P	G
Acetone	G	G		P	G	G
Ammonium Hydroxide	G	P	G	G		G
Aqua Regia	P	P		P		P
Benzene	G	G		P	G	G
Carbon Tetrachloride	G	F		F	G	G
Chloroform	G	F		P	P	G
Citric Acid	G	F			G	G
Dimethylformamide	F	F				F
Ethyl Acetate	G	G			G	G
Ethyl Alcohol	G	G		G		G
Ethyl Ether	G	G		P	G	G
Ethylene Dichloride	G	F		P		F
Ethylene Glycol	G	F	G	G		G
Formaldehyde	G	G			G	G
Formic Acid	P	P				F
Freon	G	F		F	P	G
Gasoline	G	G		F	G	G
Heptane	G	G	G	G	G	G
Hexane	G	G		G	G	G
Hydrochloric Acid	P	P	G	F	P	F
Hydrogen Peroxide	F	P		G	P	G
Kerosene	G	G				G
Linseed Oil	G	G				G
Methyl Alcohol	G	G		P		G
Methyl Ethyl Ketone	G	G			G	G
Mineral Oils	G	G			G	G
Nitric Acid	P	P	G	G		P
Oleic Acid	G	F		G	G	G
Phenol	F	P		P	P	P
Phosphoric Acid	P	P		G	P	F
Soap Solutions	G	G			G	G
Sodium Carbonate	G	G		G	G	G
Sodium Chloride	G	G		G	G	G
Sodium Hydroxide	G	P	G		G	F
Sodium Hypochlorite	F	P	G	G		
Sodium Thiosulfate	G	F			G	
Sulfuric Acid	P	P	G	G	P	F
Toluene	G	F		P	G	G
Water	G	G		G	G	G

F = Fair P = Poor G = Good GP = General Purpose HS = Heat Stabilized

Thermal Resistance

Since Celanex thermoplastic resin is a crystalline polymer possessing a distinct melting point, there is little change in dimensional stability until the melting point temperature is reached. This characteristic, combined with the excellent resistance to thermal degradation and outstanding electrical properties at high temperatures, makes Celanex polyester ideal for applications where high temperature exposure is expected. Consequently, it is used extensively in under-the-hood automotive applications where temperatures of 149°C (300°F) are common. Celanex polyester is also used in high performance electrical devices taking advantage of the UL temperature index as high as 140°C (284°F) and resistance to 288°C (550°F) solder.

Figure 5.2 shows the percent dimensional change after 149°C (300°F) aging for six months. These results are excellent when compared to some high temperature thermosetting plastics that change up to 1.0% over the same time period.

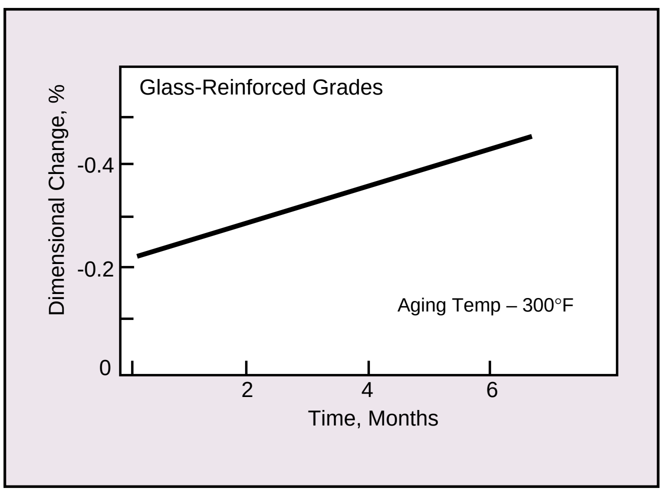


Figure 5.2 Dimensional Effects on Heat Aging on Glass Reinforced Celanex Polyester

Weathering Resistance

Celanex polyester exhibits inherently excellent resistance to degradation by ultraviolet radiation and outdoor weathering.

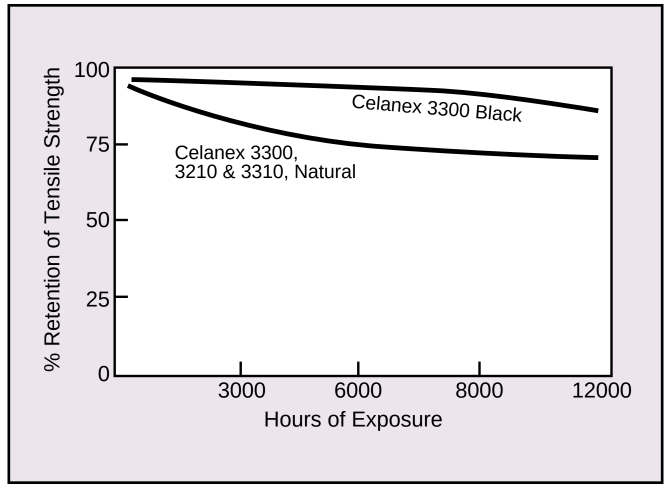


Figure 5.3 Weatherometer Exposure Effects on Tensile Strength, Glass Reinforced Grades of Celanex® Thermoplastic Polyester

Laboratory Weatherometer testing on moldings of unpigmented and pigmented Celanex polyester shows relatively little loss of tensile properties. Figure 5.3 shows the percent of original tensile strength retained after weatherometer (carbon arc) aging for 12000 hours (approximately 1-3/8 years).

Since weather varies from day to day, year to year, and place to place, no precise correlation exists between artificial laboratory weathering and natural outdoor weathering. However, standard laboratory test conditions (based on experience with testing materials of known weatherability) can produce acceptable results that generally agree with data obtained from outdoor exposure. There is no laboratory method for precisely predicting outdoor weatherability on materials with no previous weathering history.

Black Celanex 3300 resin exhibits better property retention than natural and should be considered where long-term outdoor exposure is required. Figures 5.4 and 5.5 show tensile strength and notched Izod impact strength after approximately 12 months of exposure.

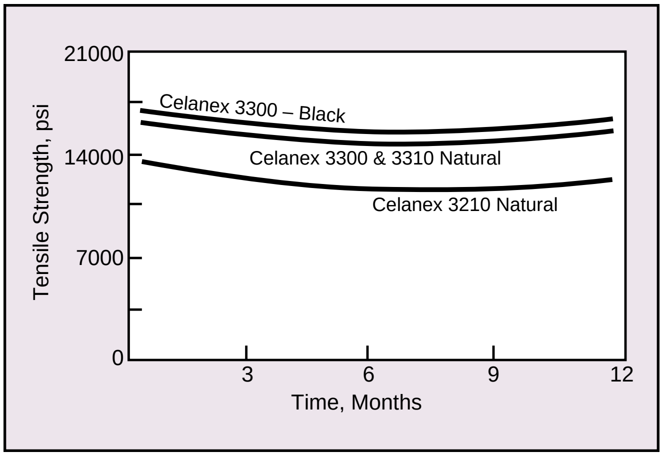


Figure 5.4 Tensile Strength Versus Outdoor Exposure in Florida and Arizona, Glass Reinforced Grades of Celanex® Thermoplastic Polyester

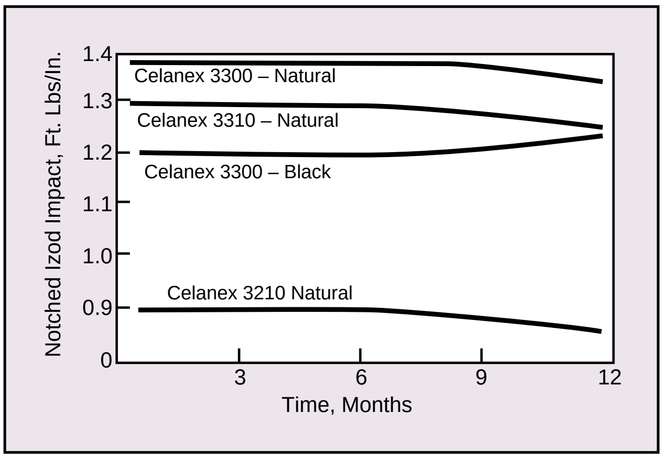


Figure 5.5 Izod Impact Versus Outdoor Exposure in Florida and Arizona, Glass Reinforced Grades of Celanex® Thermoplastic Polyester

Outdoor Weatherability of UV Black Celanex Resins - Plaques of Celanex grades 1462Z BK225, 6500 BK225, 6407 ED3807, and 2002-2 ED3807 were tested for outdoor weatherability. They were exposed in South Florida for 2 years, facing 5° south using an open back rack mounting system according to method SAE J1976. Samples were hosed monthly on the racks.

Two sets of color difference measurements were made for each sample. The first was “as is”, where the color measurement was made on the untouched, unwashed specimen. Then the sample was washed using a solution of two grams of No. 7 Car Wash concentrate in one liter deionized water and re-measured. The color difference values were labeled as “washed” values.

For grades 6500 BK225 and 2002-2 ED3807, a third measurement was taken after the sample was polished with No. 7 Auto Polish and Cleaner. That color difference was labeled as “washed and polished”.

Exposure was generally performed on a high gloss surface. This type of surface is the most difficult to stabilize and maintain in weathering studies.

A summary of color differences and gloss change data is provided in Table 5.4.

Table 5.4 Polyesters - Color Difference & Gloss Change, 2 Years Exposure; SAE J1976; South Florida

						60% Gloss Readings (%)		
Celanex Grades	**Condition**	**ΔL**	**Δa**	**Δb**	**ΔE**	**Initial**	**Final**	**Retention**
1462Z BK225	As Is	-3.62	0.20	0.87	3.73	24.0	5.0	20.8
	Washed	0.62	0.04	0.49	0.80	24.0	10.3	42.9
6500 BK225	As Is	-5.05	0.25	0.61	5.09	88.0	14.4	16.4
	Washed	0.43	0.02	0.02	0.43	88.0	36.8	41.8
	Washed & Polished	-3.26	0.01	-0.39	3.29	88.0	25.3	28.8
6407 ED3807	As Is	-1.35	-0.15	0.12	1.36	44.5	3.2	7.2
	Washed	0.50	0.04	0.69	0.85	44.5	17.4	39.1
2002-2 ED3807	As Is	-6.58	0.53	1.34	6.74	92.3	29.5	32.0
	Washed	-0.70	-0.01	0.39	0.80	92.3	67.7	73.3
	Washed & Polished	-0.39	-0.09	-0.54	0.67	92.3	71.8	77.8

Δ means the change in the value (i.e., the exposed value minus the initial value)

Xenon Arc, Color and Mechanical Property Retention - Celanex grades 6500 BK225, 2002-2 ED3807, and 6407 ED3807 were exposed to 2500 kJ/m^2 of Xenon Arc and then tested for retention of color and mechanical properties. Table 5.5 shows color retention data for these three grades of Celanex. Table 5.6 shows mechanical property retention for grades 6500 BK225 and 6407 ED3807 (2002-2 ED 3807 was not tested).

Table 5.5 Prototype Parts (Xenon Arc; 2500 kJ/m^2; SAE J1960) - Color Difference & 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 5.6 Mechanical Property Retention After Exposure - Xenon Arc; 2500 kJ/m^2; 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

Vandar® Thermoplastic Polyester Alloys

Chemical Resistance

Most grades of Vandar thermoplastic polyester alloys have chemical resistance behavior similar to Celanex thermoplastic polyester. However, the performance of specific grades of Vandar polyester alloys differs from Celanex polyesters because of the compositions of specific Vandar alloys. For more information, contact Product Information Services.

Thermal Resistance

Information on the mechanical performance of selected grades of Vandar at elevated temperature is provided in Chapter 3.

Relative Thermal Index (RTI) ratings (formerly known as continuous use temperatures) for selected grades of Vandar are provided in Chapter 2, Table 2.4. The RTI ratings for Vandar thermoplastic alloys are as high as 130°C.

For more information on thermal resistance, contact Product Information Services.

Weathering Resistance

Weatherable black grades of Vandar alloys, such as Vandar 4612R BK225, are available to help prevent premature degradation from exposure to UV light. Contact Product Information Services for details.

Impet® Thermoplastic Polyester Chemical Resistance

Impet thermoplastic polyesters possess superior resistance when exposed to acids and bases at room temperature. However, chemical attack will occur at elevated temperature.

Impet polyester also has excellent resistance to a variety of fluids which include:

- Gasoline, motor oil and transmission fluid
- Hydrocarbons
- Organic solvents

Exposure of Impet polyester to ketones and esters may cause plasticization and small dimensional changes.

Qualitative chemical resistance ratings are provided in Table 5.7. These ratings are for room temperature exposure of PET compounds.

Table 5.7 Chemical Resistance Ratings for PET Compounds

Chemical	Rating
Organic Acids and Anhydrides	
Acetic Anhydride	S
Acetic Acid (10%)	S
Acetic Acid (Glacial)	S
Butyric Acid	S
Chloroacetic Acid	L
Citric Acid (10%)	S
Formic Acid (90%)	S
Oleic Acid	S
Oxalic Acid (Solutions)	S
Trichloroacetic Acid	U
Alcohols	
Amyl Alcohol	S
Benzyl Alcohol	S
Butanol	S
Cyclohexanol	S
Ethanol	S
Iso-propanol	S
Methyl Alcohol	S
Propanol	S

Table 5.7 Chemical Resistance Ratings for PET Compounds (Continued)

Chemical	Rating
Glycols	
Diethylene Glycol	S
Ethylene Glycol	S
Glycerol	S
Aldehydes and Ketones	
Acetaldehyde	S
Benzaldehyde	L
Formaldehyde	S
Acetone	S
Acetophenone	L
Cyclohexanone	S
Methyl Ethyl Ketone	S
Esters and Ethers	
Amyl Acetate	L
Butyl Acetate	S
Dioctyl Phthalate	L
Ethyl Acetate	U
Tricresyl Phosphate	S
Diethyl Ether	U
Hydrocarbons - Aliphatic	
Gasoline	S
Hexane	S
ISO-octane	S
Hydrocarbons - Alicyclic	
Cyclohexane	S
Decalin	L
Tetralin	S
Hydrocarbons - Aromatic	
Benzene	S
Toluene	L
Xylene	L
Hydrocarbons - Halogenated	
Benzyl Chloride	S
Butyl Chloride	L
Carbon Tetrachloride	S
Chlorobenzene	L

Rating Key:

S = Satisfactory for room temperature exposure.
L = Limited room temperature exposure.
U = Unsatisfactory for room temperature exposure.

Table 5.7 Chemical Resistance Ratings for PET Compounds (Continued)

Chemical	Rating
Hydrocarbons - Halogenated (Continued)	
Chloroform	S
Ethyl Chloride	L
Ethylene Dichloride	S
Methylene Chloride	U
Perchloroethylene	S
Trichloroethane	U
Trichloroethylene	U
Vinyl Chloride	S
Alkalis	
Ammonium Hydroxide (35%)	S
Potassium Hydroxide (50%)	S
Sodium Hydroxide (10%)	S
Sodium Hydroxide (60%)	S
Amines	
Aniline	L
Butyl Amine	L
Diethyl Amine	S
Triethanol Amine	S
Halogens	
Bromine (Liquid)	L
Chlorine (Gas-Dry)	S
Chlorine Dioxide	S
Chlorine Water	U
Fluorine (Gas)	U
Sodium Hypochlorite (20%)	S
Heterocyclics	
Dioxane	S
Furfural	L
Pyridine	U
Tetrahydrofuran	S
Mineral Acids - Concentrated	
Hydrobromic Acid (50%)	S
Hydrochloric Acid (36%)	S
Hydrofluoric Acid (40%)	L
Sulfuric Acid (70%)	L
Mineral Acids - Dilute	
Hydrochloric Acid (10%)	L
Nitric Acid (10%)	L
Sulfuric Acid (10%)	S

Table 5.7 Chemical Resistance Ratings for PET Compounds (Continued)

Chemical	Rating
Mineral Acids - Oxidizing Agents	
Aqua Regia	U
Chlorosulfonic Acid	U
Chromic Acid	U
Nitric Acid (70%)	U
Sulfuric Acid (96%)	U
Sulfuric Acid (Fuming)	U
Mineral Acids - Weak	
Boric Acid	S
Miscellaneous Inorganics	
Hydrogen Peroxide (35%)	S
Hydrogen Sulfide (Gas)	S
Ozone (Gas)	L
Sulfur Dioxide (Gas)	S
Miscellaneous Organics	
Acetonitrile	L
Acetyl Chloride	L
Carbon Disulfide	L
Dimethyl Formamide	S
Nitrobenzene	S
Mineral Oils and Fuels	
ASTM Oil No. 1	S
ASTM Oil No. 2	S
ASTM Oil No, 3	S
Diesel Oil	S
Lubricating Oil	S
Paraffin Oil	S
Transformer Oil	S
Natural Oils	
Caster Oil	S
Linseed Oil	S
Olive Oil	S
Rapeseed Oil	S
Vegetable Oils (General)	S
Phenols	
Cresols	U
Phenol	U

Rating Key:

S = Satisfactory for room temperature exposure.
L = Limited room temperature exposure.
U = Unsatisfactory for room temperature exposure.

Table 5.7 Chemical Resistance Ratings for PET Compounds (Continued)

Chemical	Rating
Refrigerants and Industrial Fluids	
Cellosolve	S
Freon-11	S
Freon-113	S
Freon-115	S
Freon-12	S
Freon-13B1	S
Freon-21	S
Freon-22	S
Freon-32	S
Turpentine	L
Wine	S
Water and Aqueous Salts	
Aluminum Chloride (10%)	S
Aluminum Sulfate	S
Ammonium Sulfate (50%)	S
Barium Chloride	S
Calcium Chloride	S
Copper Sulfate	S
Ferric Chloride	S
Magnesium Chloride	S
Nickel Chloride	S
Potassium Permanganate (25%)	S
Potassium Sulfate	S
Silver Nitrate	S
Sodium Borate	S
Sodium Carbonate (10%)	S
Sodium Chloride (25%)	S
Sodium Nitrate	S
Stannic Chloride	S
Water (Distilled)	S
Water (Sea)	S
Zinc Chloride (Aqueous Solution)	S

Rating Key:

S = Satisfactory for room temperature exposure.
L = Limited room temperature exposure.
U = Unsatisfactory for room temperature exposure.

Thermal Resistance

Impet polyesters possess excellent resistance to thermal degradation. They have slightly higher temperature limits than Celanex polyesters. With UL temperature index ratings as high as 150°C (302°F), Impet polyester is ideal for many under-the-hood automobile applications.

Weathering Resistance

Weatherable grades of Impet, specifically developed for use in unpainted outdoor applications, exhibited significantly less surface deterioration and color fade when tested against conventional Impet grades.

Weatherable and conventional grades of Impet polyester were exposed to outdoor conditions in direct sunlight for 2 years in South Florida. Testing was conducted according to method SAE J1976 at a rigorous angle of 5° facing South resulting in the following visual observations:

- Weatherable grades of Impet showed superior color retention (lower color difference and less change) and much better surface appearance than the conventional Impet grades.

Test results also indicated that the weatherable Impet resins maintained over 95% of their initial tensile strength and flexural strength properties. Mechanical property retention after exposure was determined using accelerated automotive test cycle SAE J1960. This test employs the Xenon Arc weatherometer with exposure up to 2500 kJ/m^2.

Riteflex® Thermoplastic Polyester Elastomers

Chemical Resistance

Reagents have many different effects on polymeric materials. Some reagents are absorbed, some dissolve the polymer, and some cause decomposition or embrittlement in varying degrees. The response of a thermoplastic polyester elastomer to a specific chemical can vary significantly depending on the grade of polyester elastomer, type and length of exposure, and temperature.

Chemical resistance ratings for Riteflex elastomers shown in Table 5.8 are based on:

- Some actual testing and general knowledge of the chemical resistance behavior of other polyester materials.
- General knowledge of the rated chemicals and how they affect various materials.

Note: The "Rating" column in Table 5.8 contains Shore D Hardness values in parenthesis for some of the chemicals listed. These values relate to specific grades of Riteflex. For example, 40 is the Shore D hardness value for Riteflex Grade 640.

It is strongly recommended that prototype parts be tested under end use conditions and evaluated to verify the ratings provided in Table 5.8.

Table 5.8 Chemical Resistance Ratings for Riteflex® Thermoplastic Polyester Elastomers

Chemical	Rating	Chemical	Rating
Acetic Acid 20-30%	E	Benzene	G (40,55D)
Acetic Acid, Glacial	E	Benzene	E(77D)
Acetic Anhydride	W	Bromine, Anhydrous Liquid	NR
Acetone	G	Butane	E
Acetylene	E	Butyl Acetate	G (40,55D)
Aluminum Chloride Solutions	W	Butyl Acetate	E (77D)
Aluminum Sulfate Solutions	W	Calcium Chloride Solutions	E
Ammonium Hydroxide	W	Calcium Hydroxide Solutions	W
Aniline	NR	Carbon Dioxide	E
ASTM Oil No. 1 (149°C)	E	Carbon Monoxide	E
ASTM Oil No. 3 (149°C)	E	Carbon Tetrachloride	NR (40D)
ASTM Reference Fuel A	E	Carbon Tetrachloride	B(55D)
ASTM Reference Fuel B (70°C)	E	Carbon Tetrachloride	E(77D)
ASTM Reference Fuel C	E	Chlorine Gas, Wet & Dry	NR
ASTM Reference Fuel C (70°C)	G (40,55D)	Chloroacetic Acid	NR
ASTM Reference Fuel C (70°C)	E(77D)	Chlorobenzene	NR
Asphalt	W	Chloroform	NR (40, 55D)
Barium Hydroxide Solutions	W	Chloroform	G (77D)
Beer	E	Chlorosulfonic Acid	NR

Rating Key:

E: No adverse reaction, little or no absorption, little or no effect on mechanical properties
G: Some effect, some absorption causing slight swelling and reduction in mechanical properties.
W: No data. Available information suggests little absorption and little effect on mechanical properties.
NR Not recommended, material adversely affected in a short time.

Table 5.8 Chemical Resistance Ratings for Riteflex® Thermoplastic Polyester Elastomers (Continued)

Chemical	Rating	Chemical	Rating
Acetic Acid 20-30%	E	Benzene	G (40,55D)
Citric Acid Solutions	E	Lacquer Solvents	E (77D)
Copper Chloride Solutions	E	Linseed Oil	NR
Copper Sulfate Solutions	E	Magnesium Chloride Solutions	NR
Cyclohexane	E	Magnesium Hydroxide Solutions	NR
Dibutyl Phthalate	E	Methyl Alcohol	E
Diethyl Sebacate	E	Methyl Ethyl Ketone	G (40,55D)
Dioctyl Phthalate	E	Methyl Ethyl Ketone	E (77D)
Epichlorohydrin	NR	Methylene Chloride	NR
Ethyl Acetate	G (40,55D)	Mineral Oil	E
Ethyl Acetate	E (77D)	Naphtha	E
Ethyl Alcohol	E	Naphthalene	G (40,55D)
Ethyl Chloride	NR (40,55D)	Naphthalene	E (77D)
Ethyl Chloride	G (77D)	Nitric Acid 10%	G
Ethylene Dichloride	NR (40,55D)	Nitric Acid 30 - 70%	NR
Ethylene Dichloride	G (77D)	Nitric Acid, Red Fuming	NR
Ethylene Glycol	E	Nitrobenzene	NR
Ethylene Oxide	E	Oleic Acid	E
Ferric Chloride Solutions	G	Oleum 20 - 25%	NR
Formaldehyde 40%	G	Palmitic Acid	E
Formic Acid	G	Perchloroethylene	NR (40,55D)
Freon 11, 12, 114	E	Perchloroethylene	E (77D)
Freon 113 (54°C)	E	Phenol	NR
Gasoline	E	Pickling Solution (20% Nitric Acid, 4% HF)	NR
Glycerin	E	Potassium Dichromate Solutions	W
n-Hexane	E	Potassium Hydroxide Solutions	E
Hydrochloric Acid 20%	G	Pyridine	NR
Hydrochloric Acid 37%	NR	SAE 10 Oil	E
Hydrofluoric Acid 48%, 75%	NR	Sea Water	E
Hydrofluoric Acid Anhydrous	NR	Silicone Grease	E
Hydrogen	E	Skydrol 500B	E
Isooctane	E	Soap Solutions	E
Isopropyl Alcohol	E	Sodium Chloride Solutions	E
JP-4 Jet Fuel	E	Sodium Dichromate 20%	W
Kerosene	NR	Sodium Hydroxide 20%	E
Lacquer Solvents	G (40, 55D)	Sodium Hydroxide 46%	

Rating Key:

E: No adverse reaction, little or no absorption, little or no effect on mechanical properties
G: Some effect, some absorption causing slight swelling and reduction in mechanical properties.
W: No data. Available information suggests little absorption and little effect on mechanical properties.
NR Not recommended, material adversely affected in a short time.

Table 5.8 Chemical Resistance Ratings for Riteflex® Thermoplastic Polyester Elastomers (Continued)

Chemical	Rating	Chemical	Rating
Stannous Chloride 15%	W	Toluene	G 40,55D)
Steam (100°C)	F	Toluene	E (77D)
Steam (110°C)	NR	Trichloroethylene	NR (40,55D)
Stearic Acid	W	Trichloroethylene	G (77D)
Sulfur Dioxide, Liquid	W	Triethanolamine	NR
Sulfur Dioxide, Gas	W	Trisodium Phosphate Solution	E
Sulfuric Acid 50%	E	Tung Oil	G
Sulfuric Acid 50%	NR	Water (70°C)	G
Sulfurous Acid	G	Water (100°C)	F
Tannic Acid 10%	E	Xylene	G (40,55D)
Tetrahydrofuran	G (40,55D)	Xylene	E (77D)
Tetrahydrofuran	E (77D)	Zinc Chloride Solutions	E

Rating Key:

E: No adverse reaction, little or no absorption, little or no effect on mechanical properties
G: Some effect, some absorption causing slight swelling and reduction in mechanical properties.
W: No data. Available information suggests little absorption and little effect on mechanical properties.
NR Not recommended, material adversely affected in a short time.

Electrical Properties

Introduction

Excellent electrical properties over wide temperature ranges make Celanex®, Vandar®, and Impet® thermoplastic polyester compounds ideal for use in many critical electrical and electronic applications. Electronic parts withstand a wider range of adverse conditions with much less probability of parallel circuits being formed (voltage leakage). Low moisture absorption with good electrical properties and structural integrity over a wide thermal range permit DIP manufacturers to use polyester compound as a carrier during their rigorous testing procedures.

Because of excellent solvent resistance, electronic components made of Celanex, Vandar and Impet compounds can easily be degreased using alcohols, fluorinated solvents, and trichloroethylene.

Colored materials (precompounded or prepared with standard color concentrates) retain the excellent electrical characteristics of the natural colored compound. This characteristic is acknowledged by Underwriters Laboratories (UL) in their “All Color Approval” for many of the grades listed in Table 2.4, Chapter 2.

Electrical properties for representative grades of Celanex, Vandar, and Impet resins are shown in Tables 6.1 through 6.3. For information on other grades, refer to the appropriate publication listed under “Reference Publications” in Chapter 1.

Table 6.1 Electrical Properties of Celanex® Thermoplastic Polyester

Property	Method	Units	Grades and Property Values			
			2002	2016	3200	3216
ISO Data						
Volume Resistivity, 1 mm	IEC 93	ohm-cm	10^{15}	10^{15}	10^{15}	10^{15}
Dielectric Strength, 3 mm	IEC 243-1	Kv/mm	15	>29	16	21
Permittivity, 1 MHz, 3 mm	IEC 250		3.2	3.2	3.5	3.3
Dissipation Factor, 1 MHz, 3 mm	IEC 250		0.02	0.02	0.01	0.02
ASTM Data						
Volume Resistivity	D257	ohm-cm	$>10^{16}$	$>2 \times 10^{16}$	$>10^{16}$	2×10^{16}
Dielectric Strength, 1/8”, 50% RH, 73°F	D149	V/mil	420	>700	460	600
Dielectric Constant 100 kHz	D150		3.2	3.0	3.5	2.9* (3.2)
Dissipation Factor 100 kHz	D150		0.002	0.01	0.001	(0.01)

Value at 1kHz

Table 6.1 Electrical Properties of Celanex® Thermoplastic Polyester (Continued)

Property	Method	Units	Grades and Property Values		
			3300	3316	7700
ISO Data					
Volume Resistivity, 1 mm	IEC 93	ohm-cm	10^{15}	10^{15}	10^{15}
Dielectric Strength, 3 mm	IEC 243-1	Kv/mm	31	20	18
Permittivity, 1 MHz, 3 mm	IEC 250		3.7	3.5	3.7
Dissipation Factor, 1 MHz, 3 mm	IEC 250		0.02	0.01	0.01
ASTM Data					
Volume Resistivity	D257	ohm-cm	$>10^{16}$	$>2 \times 10^{16}$	$>10^{16}$
Dielectric Strength, 1/8”, 50% RH, 73°F	D149	V/mil	560	>500	602
Dielectric Constant 100 kHz	D150		3.7	3.7	(3.7)
Dissipation Factor 100 kHz	D150		0.002	(0.02)	0.009

Table 6.2 Electrical Properties of Vandar® Thermoplastic Polyester Alloys

Property	Method	Units	Grades and Property Values			
			4361	4602Z	4612R	4662Z
ASTM Data						
Dielectric Strength, 1/8”, 50% RH, 73°F	D149	V/mil	540	360	360	584
Dielectric Constant 100 Hz (1 MHz)	D150		3.6	(3.2)	3.6	(3.9)
Dissipation Factor 100 Hz (1 MHz)	D150		0.01	(0.0055)	(0.0047)	(0.0053)

Table 6.3 Electrical Properties of Impet® Thermoplastic Polyester

Property	Method	Units	Grades and Property Values			
			330R	340R	740	830R
ASTM Data						
Volume Resistivity	D257	ohm-cm	3.0	1.0		1.0
Dielectric Strength, 1/8”, 50% RH, 73°F	D149	V/mil	565	540	440	450
Dielectric Constant 100 Hz (1 MHz)	D150		3.1	3.4	3.9	3.7
Dissipation Factor 100 Hz (1 MHz)	D150		0.016	0.012	0.010	0.016

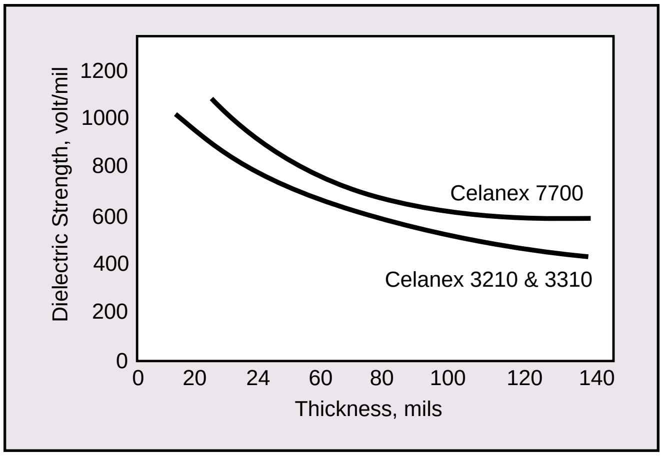


Figure 6.1 Dielectric Strength Versus Thickness, Reinforced Flame Retardant Grades of Celanex® Thermoplastic Polyester

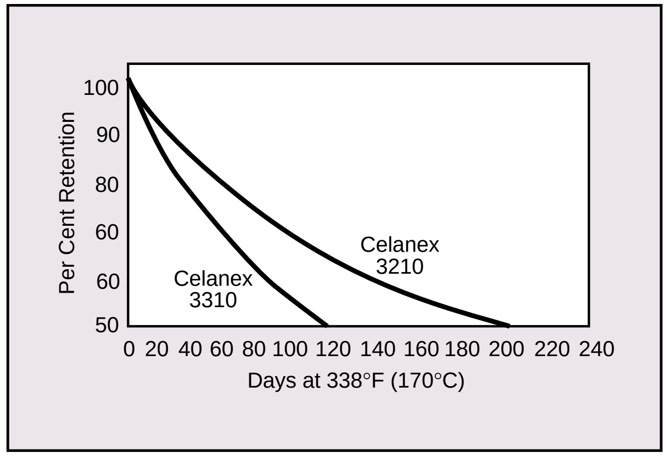


Figure 6.3 Heat Aging Effects on Tensile Strength, Reinforced Flame Retardant Grades of Celanex® Thermoplastic Polyester - 3.2 mm Thickness

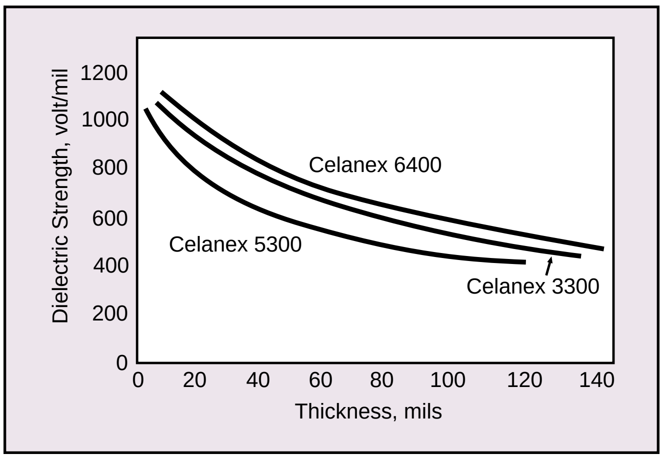


Figure 6.2 Dielectric Strength Versus Thickness, Reinforced Grades of Celanex® Thermoplastic Polyester

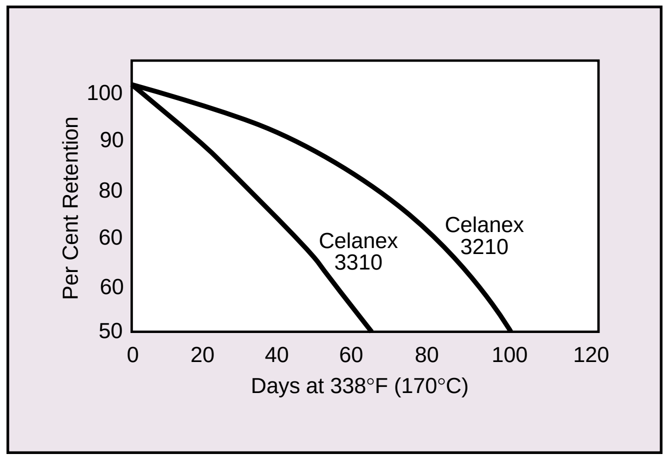


Figure 6.4 Heat Aging Effects on Dielectric Strength, Reinforced Flame Retardant Grades of Celanex® Thermoplastic Polyester - 0.8 mm Thickness

Effects of Thickness

Dielectric strength versus thickness of various grades of Celanex polyester are shown in Figures 6.1 and 6.2.

Effects of Heat Aging

High temperature aging tests have been conducted on Celanex glass reinforced compounds to determine environmental aging effects on electrical and tensile properties. As shown in Figures 6.3 through 6.6, Celanex polyester retains its excellent properties under extreme conditions. These figures illustrate the results of aging at a temperature of 170°C (338°F) on dielectric and tensile strength, respectively. Note that this temperature is higher than the UL Relative Thermal Index.

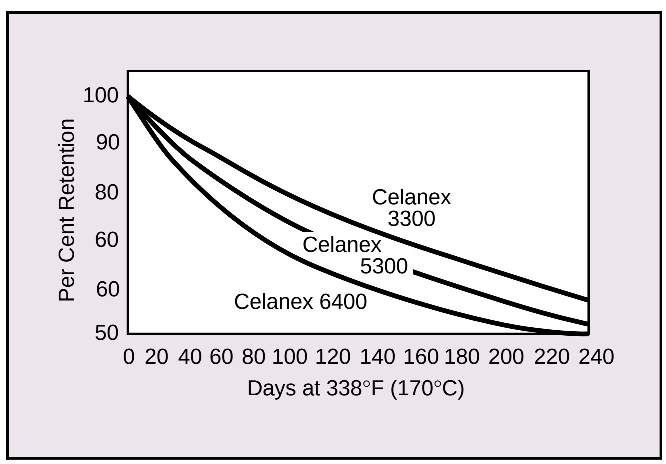


Figure 6.5 Heat Aging Effects on Tensile Strength, Reinforced Grades of Celanex® Thermoplastic Polyester - 3.2 mm Thickness

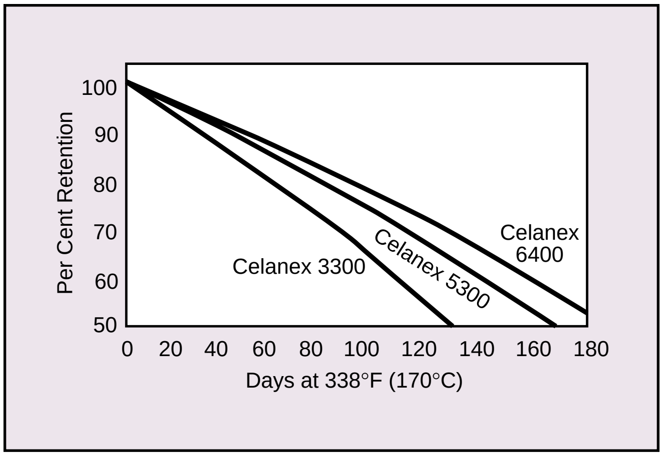


Figure 6.6 Heat Aging Effects on Dielectric Strength, Reinforced Grades of Celanex® Thermoplastic Polyester - 0.8 mm Thickness

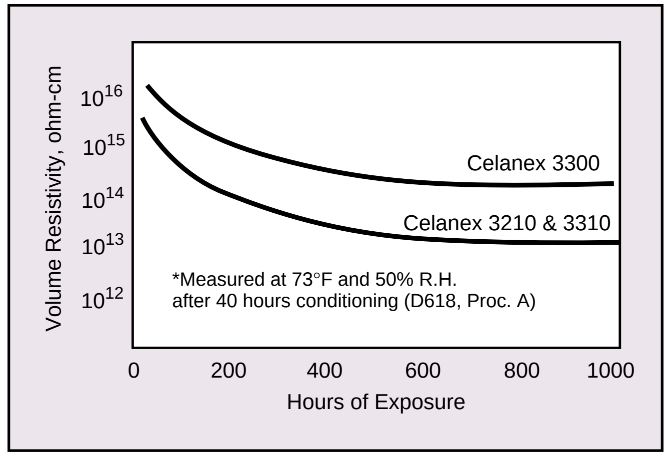


Figure 6.7 Volume Resistivity of Reinforced Grades of Celanex® Thermoplastic Polyester as a Function of Time at 70°C (158°F) and 100% Humidity

Another series of tests compared Celanex polyester to automotive grade thermosets. Celanex 3300, alkyd and phenolic, were aged at 149°C (300°F) for six months, and then tested at 23°C (73°F) for arc resistance, dielectric strength, and volume resistivity. As shown in Table 6.4, Celanex polyester maintained its balance of properties over this time period, while thermosets experienced a significant reduction in dielectric strength. Although the phenolic showed equivalence to Celanex polyester after six months exposure in the arc resistance test, it is actually far inferior in practical wet and dry arcing tests.

Table 6.4 Celanex® Thermoplastic Polyesters Versus Thermosets

	Celanex Grades				
Test and Exposure Time	**3210**	**3310**	**3300**	**Alkyd***	**Phenolic****
Arc Resistance, seconds					
Control	133	143	128	185	70
1 Month	136	147	130	192	129
2 Months	146	155	144	198	131
4 Months	127	123	140	189	129
5 Months	135	148	140	198	131
6 Months	138	150	150	195	150
Dielectric Strength Short Term, V/mil					
Control	510	510	530	410	170
1 Month	590	600	550	240	360
2 Months	580	570	530	220	350
4 Months	590	580	600	250	420
5 Months	530	530	510	270	370
6 Months	540	540	550	240	380
Volume Resistivity, ohm-cm					
Control	10^{16}	10^{16}	10^{16}	10^{15}	10^{12}
1 Month	10^{15}	10^{15}	10^{16}	10^{15}	10^{14}
2 Months	10^{15}	10^{15}	10^{16}	10^{16}	10^{15}
4 Months	10^{15}	10^{15}	10^{16}	10^{16}	10^{15}
5 Months	10^{15}	10^{15}	10^{16}	10^{16}	10^{15}
6 Months	10^{15}	10^{15}	10^{17}	10^{15}	10^{15}

** Glass/mineral filled grade.*
*** General purpose automotive electrical grade.*

Part Design Criteria

Introduction

This chapter addresses a number of key factors that should be considered in designing injection molded parts of thermoplastic polyester.

Note: For detailed information on the basic principles of plastic part design, see Chapter 8 in the publication titled "Designing With Plastic: The Fundamentals, (TDM-1)". This publication can be obtained by calling Product Information Services at 1-800-833-4882.

Material Selection

Material selection is one of the most important steps in developing a commercial product. Thermoplastic polyesters have been satisfactorily used in many applications because they combine excellent properties and easy processability. These products give more latitude to the part designer than many other thermoplastics, thermosets or metals.

Wall Thickness

Wall thickness for a given part should be kept to a minimum, as dictated by the functional requirements of the part and by the processing capabilities of the material. Thick walls in a molded part can add to the material cost, substantially lengthen the molding cycle, and increase the processing cost. In addition, thick walls can introduce problems such as internal voids and sink marks, making it less possible to maintain good quality production.

Thermoplastic polyesters possess excellent strength, toughness, and stiffness, especially when reinforced. High engineering safety factors are unnecessary so that part wall thickness can be minimized, thereby reducing part cost.

These products exhibit excellent mold flow (generally equivalent to that of nylon) and can be molded into very thin sections. Some small parts have been successfully molded into sections as thin as 0.18 - 0.20 mm (0.007 - 0.008 in.). However, the very rapid freezing rate of the material does not let it flow readily in a section this thin. Therefore, a wall thickness of 0.5 - 0.8 mm (0.020 - 0.030 in.) should be considered as a practical minimum for small to medium sized parts.

For larger parts, such as body components, wall thicknesses of 1.5 mm (0.060 in.) or greater are recommended.

Unlike nylons, polyesters retain their stiffness and cold temperature impact strength even in moist environments. Thus, where a 2.3 mm (0.090 in.) wall might be required with a 13 - 15% glass filled nylon because of impact requirements, a 1.5 - 1.8 mm (0.060 - 0.070 in.) wall in a glass reinforced polyester is adequate, resulting in material cost savings and reduced cycle time.

Thick walled parts, up to 12.7 mm (0.500 in.) thick, can be molded in polyester with proper sprue, runner, and gate design. However, thick sections should be cored to reduce excessively thick parts as much as possible consistent with adequate strength. See Figure 7.1 for an example of good and poor coring.

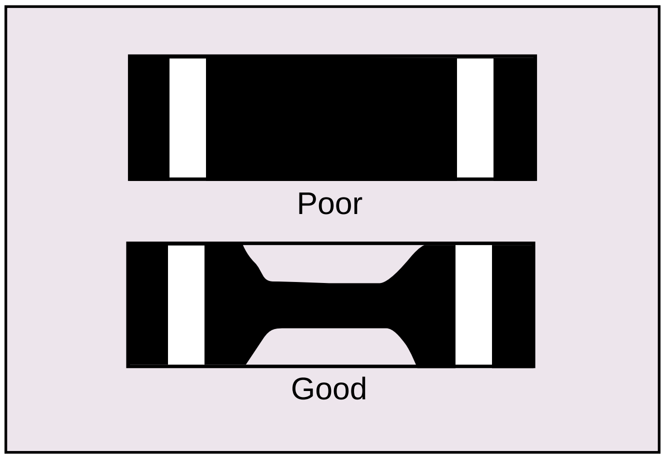


Figure 7.1 Good and Poor Coring for Thick Wall Sections

In addition to being as thin as possible, the wall thickness of the part should be uniform. Thick and thin sections within the same part can result in slight differences in densities in different sections of the part. This, combined with differences in cooling rates in thick and thin sections, can cause voids, sinks, and warpage. Figure 7.2 shows examples of uniform and nonuniform wall thicknesses. When thicker sections cannot be cored for functional reasons, gradual blending should be used between thick and thin sections. See Figure 7.3 for examples of gradual blending.

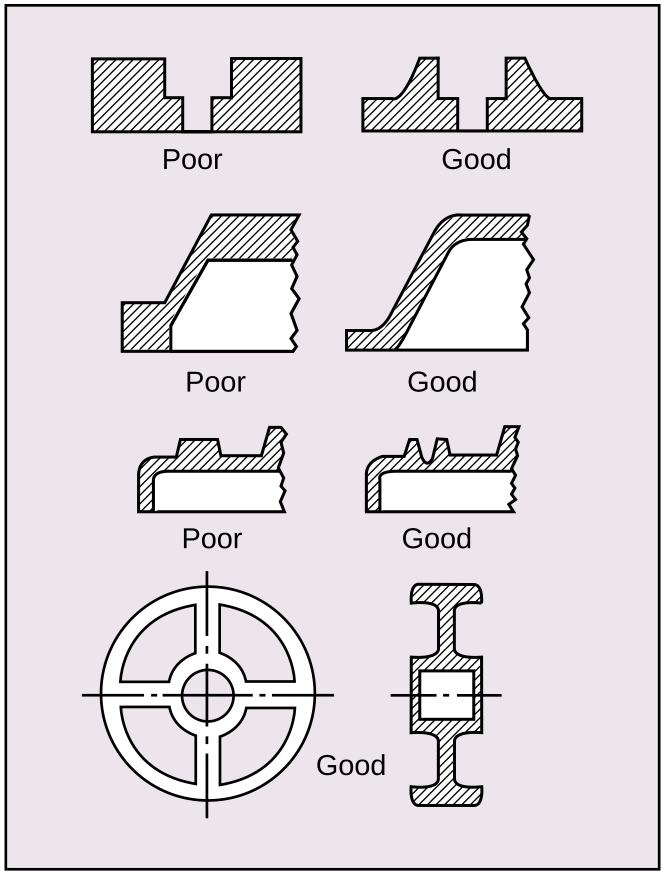


Figure 7.2 Examples of Uniform and Nonuniform Wall Thickness

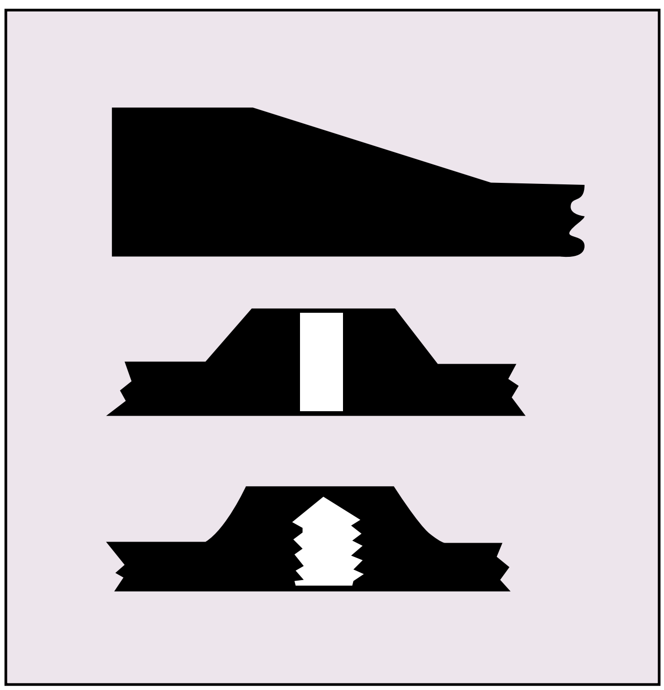


Figure 7.3 Gradual Blending Between Different Wall Sections

Ribs

Frequently, ribs are used to:

- Reduce part wall thickness, weight and cost.
- Increase part strength and stiffness.
- Improve flow paths during molding.
- Prevent part warpage.

Despite many potential advantages, careful consideration must be given to ribbing. For example, ribs can cause sink marks and induce warpage if they are not properly designed and strategically located in the part. Consequently, ribs should only be used where their benefit is reasonably certain.

For most automotive body components, the stiffness of reinforced polyester is more than satisfactory so that ribbing is not required. Where ribs are required, rib thickness should be no more than 50% of the adjacent wall thickness to prevent voids, sink marks or other distortions. To further minimize sink marks, the ribbing contour should conform to the exterior contour of the part, and the rib height should not exceed 19 mm (0.750 in.). See Figure 7.4 for rib design examples.

In applications where sink marks are not a concern, rib thickness may be 75 - 100% of the adjacent wall thickness, and they may be located in almost any area where additional strength is required. However, ribs of this thickness can change the final shape and/or dimensions of the part due to shrinkage in the ribs, which should be considered in the design.

Fillets should be used where ribs join the wall to minimize stress concentration and provide additional strength. See “Fillets and Radii” on page 7-6.

To facilitate part ejection from the mold, a 1° draft per side is desirable for all ribs (see Figure 7.5). However, a 1/2° draft per side is generally satisfactory for short ribs. In some cases, the softer Riteflex polyesters and Vandar polyesters may require draft angles as high as 2°.

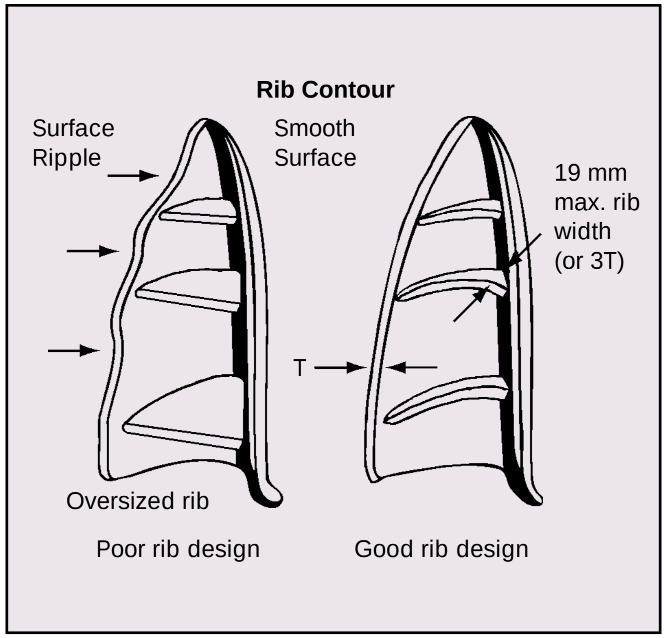


Figure 7.4 Poor and Good Rib Design

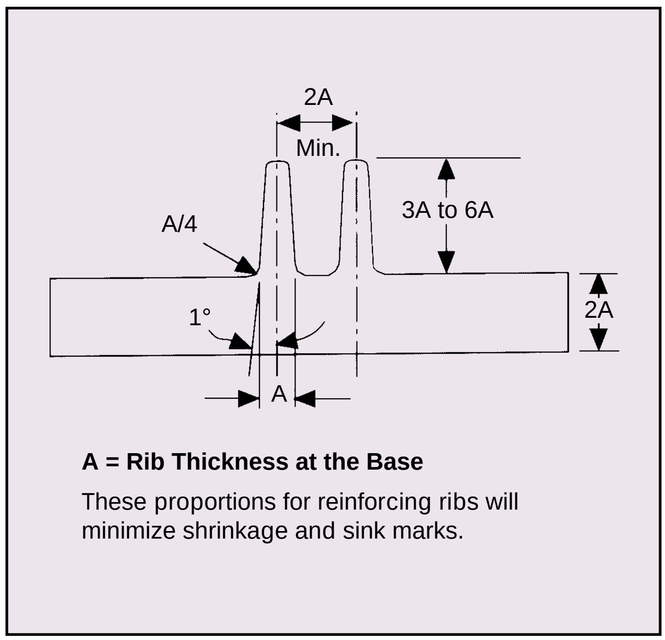


Figure 7.5 Proper Rib Proportions

Bosses and Studs

Bosses and studs are protrusions frequently used around holes for reinforcement, or as mounting or fastening points. Solid bosses are often called studs. The following guidelines should be considered when designing a boss or stud:

- The height of the boss or stud should not be more than twice the diameter.
- Provide sufficient draft to ensure easy part ejection (see Figure 7.6).
- Use a radius or fillet where the boss joins a wall section to ease fill, strengthen the area, and assist in disguising any sink marks which may be present.
- For solid bosses, use a boss diameter smaller in dimension than the thickness of the wall from which it protrudes. Because of this limitation, core out the center of bosses so that the side wall thickness is less than the main wall thickness. Again, radius the end of the core pin to eliminate sharp corners and minimize sink tendencies.
- Locate bosses and studs at the apex of the angles where the surface contour changes abruptly (see Figure 7.7). Using a bubbler on the cavity side of the mold opposite the boss will often eliminate or minimize sink on the outside wall.
- To eliminate any problems that may occur when molding long bosses and studs, provide proper venting to release air at the bottoms of the cavity holes in which they are molded.
- In designing automotive body components, size the length of the mounting boss to provide a maximum clearance of 3.2 mm (0.125 in.) between the boss and the mounting bracket or frame as shown in Figure 7.8. This prevents the mounting boss from being pulled toward the frame during assembly and causing a dimple in the exterior surface of the body component.
- Core mounting bosses located adjacent to the sidewall of a part to avoid unnecessary thick sections (see Figure 7.9).
- Use ribs to reinforce free standing bosses and to encourage flow of material into the boss.
- Use ejector sleeves for ejecting mounting bosses to prevent hang-up in the cavity. Inadequate boss ejection can contribute to sink where it joins the body of the part (see Figure 7.10). To effectively prevent hang-up, the stroke of the ejector sleeve should be at least 3/4 of the full length of the boss as shown in Figure 7.11.

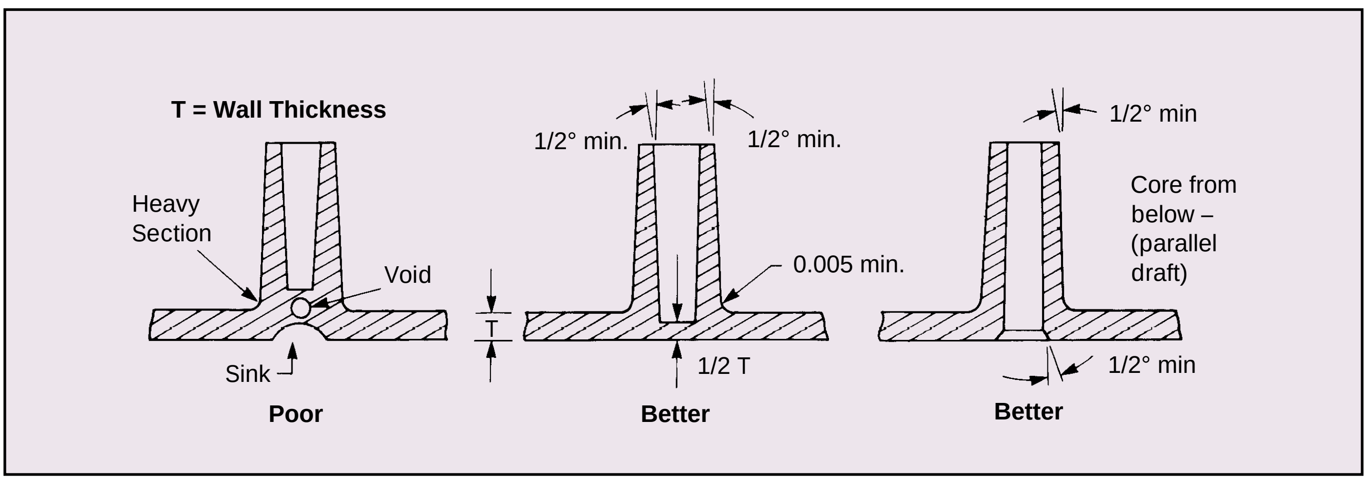


Figure 7.6 Proper Draft Angle for Bosses

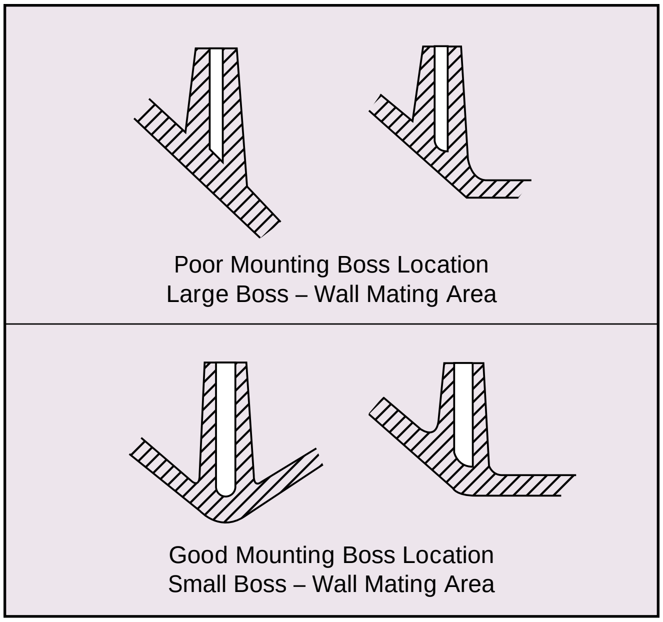


Figure 7.7 Poor and Good Boss Location

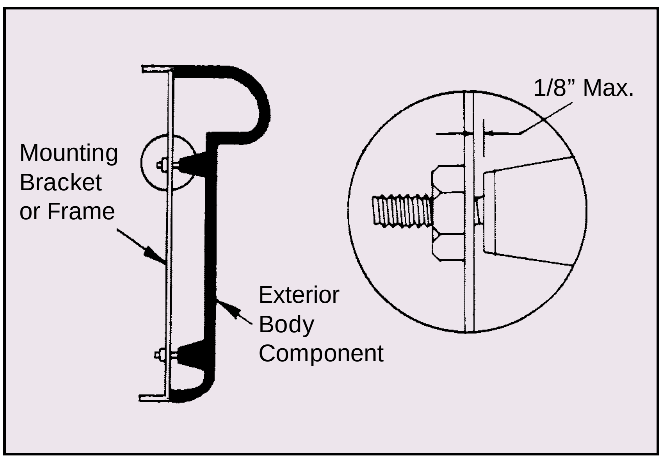


Figure 7.8 Recommended Mounting Boss Length in Mounting Bracket

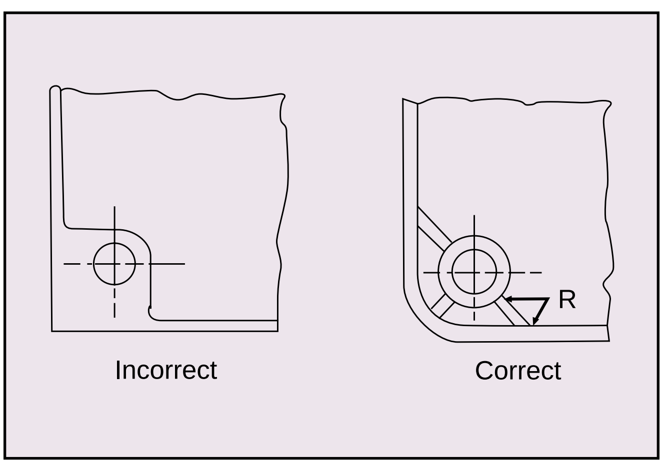


Figure 7.9 Correct and Incorrect Mounting Bosses

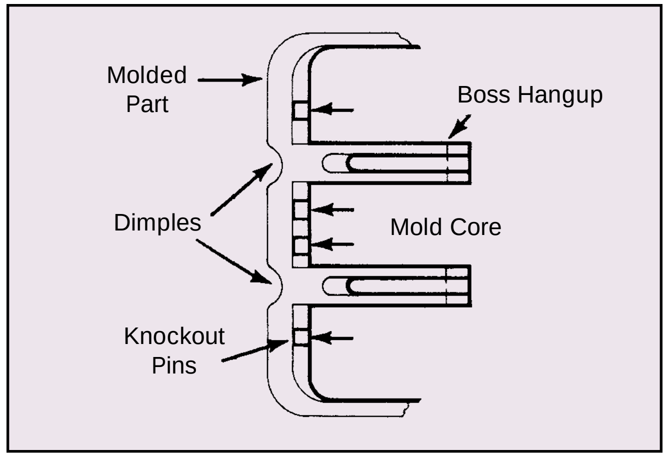


Figure 7.10 Sink Caused by Boss Hang-Up

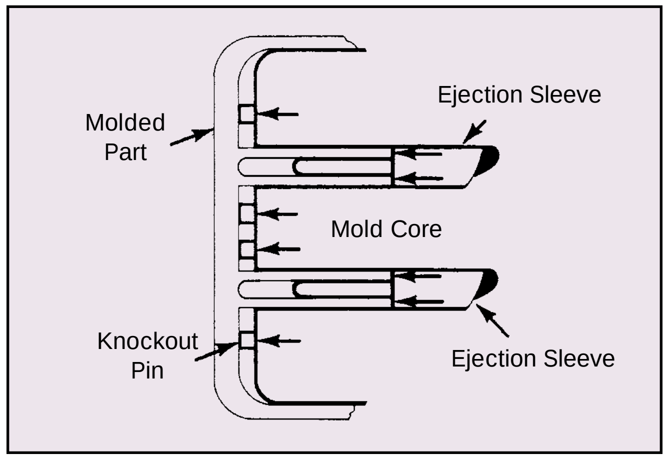


Figure 7.11 Recommended Ejector System for Bosses

Fillets and Radii

Sharp corners in injection molded plastic parts should always be avoided since they cause poor flow patterns and can lead to severe molded-in stresses and reduced mechanical properties. Fillets or radii are recommended for all corners to:

- facilitate resin flow in the mold,
- minimize stress concentration,
- permit easier part ejection from the mold.

Inside and outside corners should be rounded with a radius of 25 - 75% of the adjacent wall thickness (see Figure 7.12).

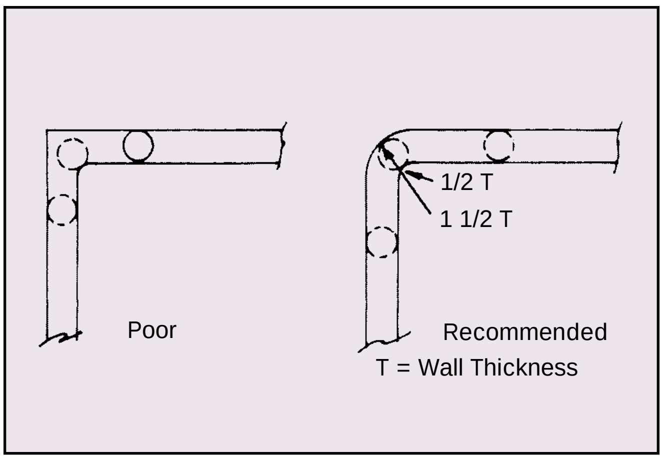


Figure 7.12 Corner Radii Recommendations

Tolerances

Dimensional tolerance can be defined as the variation above and below a nominal mean dimension. The closer the tolerance (or the narrower the limits), the more difficult and expensive it becomes to produce the part. To avoid excessive molding and processing costs without sacrificing part performance, part designers should determine if extremely tight tolerances are really necessary, and if they can be economically justified. Also, it may be unreasonable to specify close tolerances on a part that will be exposed to a wide range of in-service temperature variations, since dimensional changes (due to temperature variations) can be many times as great as specified tolerances.

Based on field molding experience and laboratory studies, dimensional tolerances which can be routinely held with Celanex and Impet thermoplastic polyester resins are:

- ±0.002 mm/mm (inch/inch) on the first 25 mm (1 inch).
- ±0.001 mm/mm (inch/inch) for each subsequent 25 mm (inch).

Depending upon part design, mold design and processing conditions, it is feasible to hold even tighter tolerances on certain dimensions.

Threads

Standard systems (Unified, Acme, etc.) can be utilized when designing threads for polyester resins. However, because of lower shear strength of this material as compared with 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 obtained are far above the actual performance requirements. Thus, by using proper thread designs, polyester resin components can be designed with the high stripping torques demanded for many applications.

Internal and external threads can be fabricated in polyester resin parts by either molding or machining in a post-molding operation. It may impossible to machine thread into the softer grades of Riteflex and Vandar polyesters. This material can be readily machined with standard metalworking tools and this procedure is generally recommended for threads below 6.4 mm (0.250 in.) diameter. Cored holes, which are to be machine-tapped after molding, should be provided with a chamfer starting from a shallow counterbore (see Figure 7.13). This will prevent chipping the edge of the hole during the tapping operation. (See also “Self-Tapping Screws”, pg 9-3 and “Threading and Tapping”, pg 10-2)

Larger internal threads may be formed by a threaded core pin which is unscrewed either manually or automatically. External threads may be formed in the mold by splitting the thread along its axis, or by unscrewing the part from the mold. When a parting line or the slightest flash on the threads cannot be tolerated, the second method (unscrewing the part from the mold) must be used. Mold designs with automatic unscrewing operations are feasible.

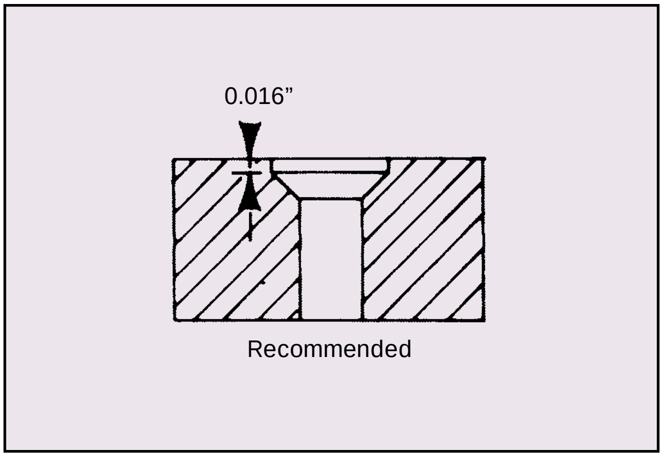


Figure 7.13 Chamfered Hole for Machine Tapping

Coarse threads are preferable to fine threads because they are easier to mold. Threads, finer than 28 pitch or closer than Class 2, should not be specified. Roots and crests of all thread types should be rounded with a radius of 0.1 - 0.3 mm (0.005 - 0.010 in.) to reduce stress concentration and provide increased strength. Chamfers, as shown in Figure 7.13, are also recommended.

Self-tapping screws can also be used successfully with polyester resins. Details are presented in Chapter 9.

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 on both ends. Since pins supported on one end can be distorted by forces exerted in molding, the depth of a blind hole should be limited to about twice the diameter.

Holes in line with the open and close action of the mold can be readily molded in thus eliminating the cost of a post-molding operation. Holes at an angle to this action, must be made by a mechanical or hydraulically-activated side core, a manually loaded and unloaded mold insert, or machining in a post-molding operation.

Between successive holes, or between the hole and a side wall, a minimum distance of one hole diameter should be allowed. If the hole is threaded, the distance should be increased to three times the diameter because of stress concentration.

Draft

Plastic parts are almost always designed with a taper in the direction of mold movement to ease ejection from the mold. This is commonly referred to as draft in the line of draw. The deeper the draw; the more draft will be required.

A draft of 1° is suggested for best results. Although some polyester parts have been successfully designed with no draft and have little problem with part ejection, a minimum taper of 1/2° per side is recommended. The softer grades of Riteflex and Vandar polyester may require draft angles up to 2°.

Surface Finish

Since polyester resin reproduces mold surfaces extremely well, a wide variety of surface finishes can be used. These are discussed in Chapter 8.

Molded-In Inserts

Polyester resin parts with molded-in inserts have achieved excellent performance results. Because of the high strength and excellent creep resistance of polyester, retention of the inserts is good, even when exposed to thermal and moisture cycling tests. Figure 7.14 illustrates poor and recommended designs for molded-in inserts.

Inserts can also be assembled via ultrasonic welding as discussed in Chapter 9.

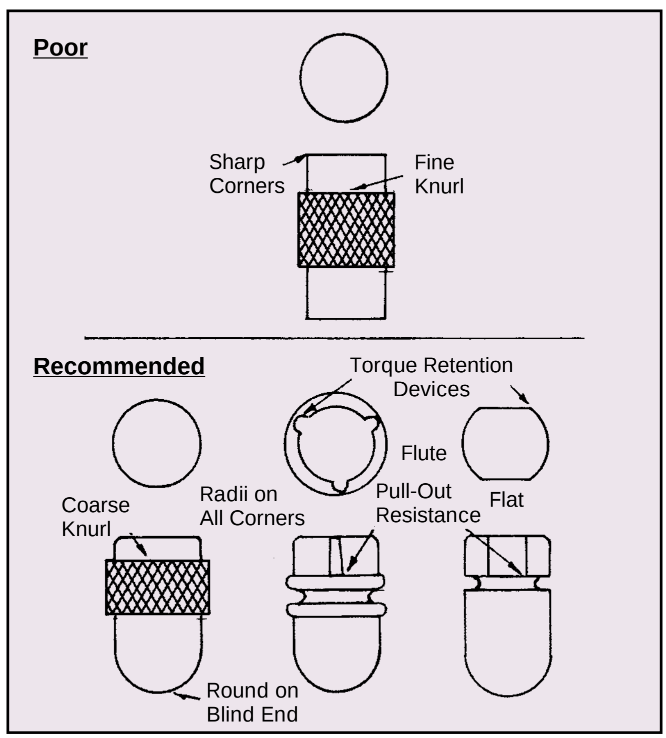


Figure 7.14 Poor and Recommended Designs for Molded-In Inserts

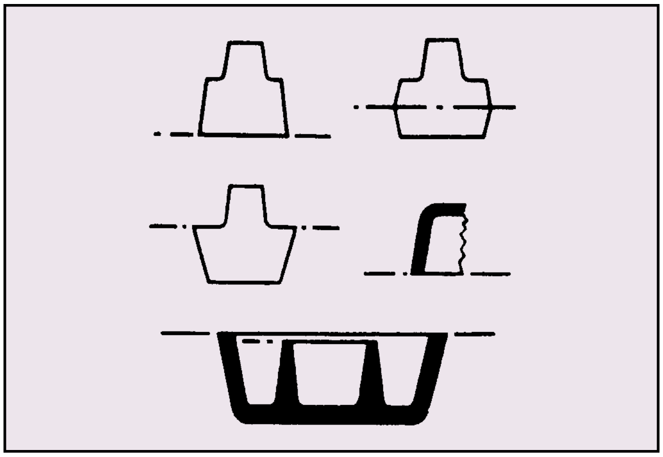


Figure 7.15 Recommended Parting Line Locations on Various Part Configurations

Parting Lines

Parting lines should be located away from aesthetically important areas without complicating mold construction. Where appearance is important, place the parting line in an area where the line will be concealed, such as an inconspicuous edge of the part, an area of changing geometry or on a shoulder. See Figure 7.15 for typical parting line locations on various part configurations.

Warpage

With all plastic materials, warpage problems may be caused by poor part design, poor mold design, improper molding conditions, or any combination of these. Glass reinforced materials are somewhat more prone to warpage problems than nonreinforced resins because of their pronounced anisotropic shrinkage behavior (differences in shrinkage in the flow and transverse directions). Glass reinforced Celanex, Vandar, and Impet polyesters are no exceptions. Most warpage problems encountered with these resins have been due to poor part design in combination with improper gate location or size.

In molding glass reinforced resin, warpage may be prevented by making the part as uniform as possible in wall thickness, selecting an optimum location for the gate and by making the gate adequate in size. For best results, locate the gate so as to achieve balanced flow in all directions and minimum flow length from the gate to the extremities of the part. Where this is impossible, locate the gate so that the flow direction is along the axis of the most critical dimension. Round parts must be gated at or near the center if concentricity is important. With some part geometries, best results are obtained with two or more gates to assure uniformity of flow and pressure transmission throughout the cavity. Recommendations on gate size keyed to part wall thickness are provided in Chapter 8.

One particular warpage situation, related to part design, is encountered frequently enough to warrant special consideration. Whenever a glass reinforced resin flows around a corner in an L-shaped or U-shaped cross section, there is a tendency for the “L” or “U” to cross inward. Analysis indicates that this is caused by the orientation of the glass fibers at the inner and outer areas of the bend. As material flows around the bend (see Figure 7.16), glass fibers in the melt stream can more freely maintain their alignment in the flow direction at the outer corner of the bend than at the inner corner. At the inner corner, the fibers bunch up and are turned crosswise or in random directions. Since glass reinforced materials shrink more in the transverse direction than in the direction of material flow, the following occurs:

- The molding shrinks slightly more at the inside corner of the bend than at the outer corner.
- The upper leg of the “L” moves inward as shown by the dashed lines in Figure 4.1. Inadequate cooling at the inside corner can produce the same results.

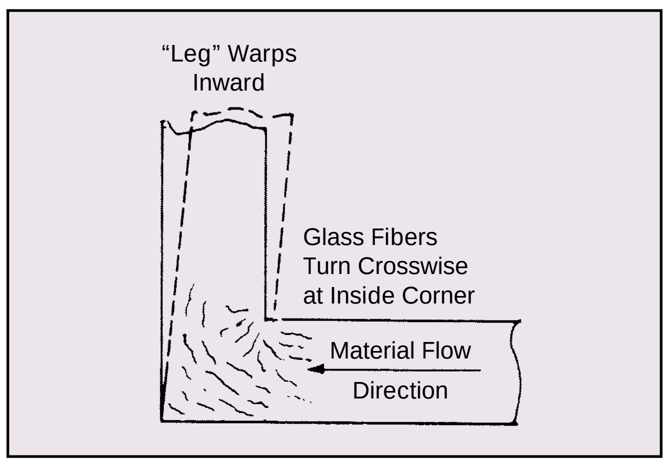


Figure 7.16 Warpage Due to Flow Around Corners

Remedies successfully used to overcome this type of warpage problem are illustrated in Figure 7.17.

In processing, warpage problems are most often caused by deficiencies in mold temperature control and/or poor pressure transmission in the cavity. The latter usually results from inadequate gate size. If moldings have reasonable symmetry in design on both sides of the parting line, best results are obtained by keeping both halves of the mold at the same temperature. Where the part is not symmetrical, and warpage is due to differences in cooling rates on both sides of the part because of geometry, warpage problems may sometimes be overcome by using different temperatures in the two halves of the mold.

Sometimes, what appears to be a warpage problem is really due to part distortion occurring when the mold opens. This is sometimes encountered in molds having inadequate draft for ease in part ejection, or where an unnoticed undercut or burr is present in the mold cavity. If suspected, this type of problem can usually be solved by slowing down the opening stroke of the press and observing whether the ejected part has reduced or zero warpage.

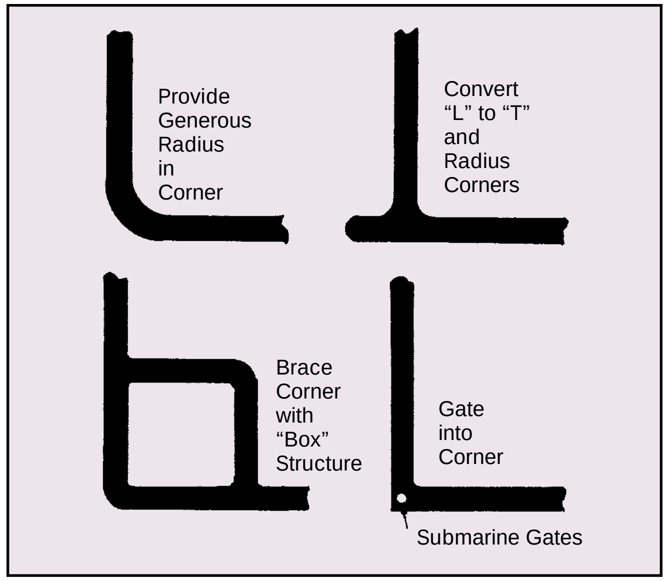


Figure 7.17 Warpage Remedies

Mold Design

Introduction
Celanex®, Vandar®, Impet®, and Riteflex® thermoplastic polyesters may be successfully molded in conventional two- and three-plate molds, stack molds, and in a wide variety of hot runner and insulated runner molds.

Mold Construction and Materials
Standard industry principals for good mold design and construction apply to the design of molds for processing thermoplastic polyesters.

Mold bases for all polyesters should be fabricated of H-13 tool steel. This popular steel combines toughness and strength with good machining and polishing qualities. Usually furnished annealed, it is hardenable to 54 Rockwell C and offers very low distortion during hardening.

Mold bases should be sturdy enough to adequately support cavities and cores without buckling the retainer plates during injection molding. They should also be large enough to accommodate cooling water channels for uniform mold temperature as discussed under “Mold Cooling” later in this chapter.

Mold Surface Finish
Since polyesters reproduce mold surfaces extremely well, a wide variety of surface finishes can be used. Part surfaces can be no glossier than the mold surface. If a high gloss Is desired, a highly polished mold surface needs to be used.

Dull or matte finishes may be created by sandblasting the mold surface. However, on prolonged molding, the flow of material over this surface may polish it resulting in a nonuniform pattern in the molded parts. As this gradually occurs, additional sandblasting may be periodically required to restore the desired surface finish.

Various designs may be created in the mold and transferred to the part by either debossing or embossing the mold surface. This process is commonly used for placing letters or numbers on parts.

Consideration should be given to location of knockout or ejector pins in the mold to avoid marks on the parts in areas where good appearance is required.

Sprue Bushings
Standard sprue bushings having a taper of 2 1/2° per side perform satisfactorily with Celanex, Vandar, Impet and Riteflex polyesters. The sprue diameter should be larger than the mating end of the molding machine nozzle to facilitate ejection of the sprue.

The end of the sprue bushing, which mates with the runner, should be equal to the diameter of the runner and be well radiused at the junction. Opposite from the junction of the sprue and the runner, provision should be made for a cold slug well and standard design sprue puller. The sprue puller pin should be kept below the runner system to prevent interference with resin flow.

Secondary sprues used for gating in 3-plate molds should have a taper of 2° - 3° included angle 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.

Conventional Runners
Full round runners are recommended, and trapezoidal are second best. Rectangular or half round runners may also be used, but they are less efficient. Suggested sizes for full round runners are provided in Table 8.1.

Generous radii should be provided in the runner system where the sprue joins the runner.

On multiple-cavity molds with primary and secondary runners, the primary runner should extend beyond the intersection of the secondary runner in order to provide a cold slug well for the runner flow front. This length should be at least equal to the basic runner diameter “D” (see Figure 8.1).

Table 8.1 Runner Size Recommendation

Part Thickness mm (in)	Runner Length mm (in)	Minimum Runner Diameter mm (in)
0.5 - 1.5 (0.020 - 0.060)	Up to 50.0 (2.0)	1.6 (0.0625)
0.5 - 1.5 (0,020 - 0.060)	Over 50.0 (2.0)	3.2 (0,125)
1.5 - 3.8 (0.060 - 0.150)	Up to 100.0 (4.0)	3.2 (0.125)
1.5 - 3.8 (0.060 - 0.150)	Over 100.0 (4.0)	4.8 (0.1875)
3.8 - 6.4 (0.160 - 0.250)	Up to 100.0 (4.0)	6.4 (0.250)
3.8 - 6.4 (0.150 - 0.250)	Over 100.0 (4.0)	7.9 (0.3125)

Runner length should be kept at a minimum. Parts requiring close dimensional control in multi-cavity molds should have balanced runner systems. Close tolerance parts should not be designed into family mold layouts.

Runnerless Molds

Continuing increases in the costs of labor, materials, etc. have been a driving force for cost reductions in processing and the production of moldings of better quality at lower prices. This, in turn, has sparked a new interest in automation including the use of runnerless molds. The increased demand for such molds has resulted in a rapid expansion of runnerless molding technology and a proliferation of commercially available runnerless molds.

Runnerless molds, as the name implies, are molds in which no sprues and runners are produced with the parts. 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 in the mold cavity and only molded parts are removed from the mold each time the press opens. No sprues or runners are produced, and therefore none need to be reprocessed as in conventional molding. Runnerless molding provides excellent opportunities for material and cost savings, with many additional benefits. Product quality and productivity can be improved, and there is little or no scrap to regrind.

Polyester compounds have been successfully molded in virtually all types of commercially available runnerless molds. As with other thermoplastic materials, runnerless molds should have adequate temperature control and be designed with generously rounded bends in the runner system. Sharp bends in the runner system, as well as other areas where resin may hang up and degrade over a period of time of elevated temperatures, should be avoided.

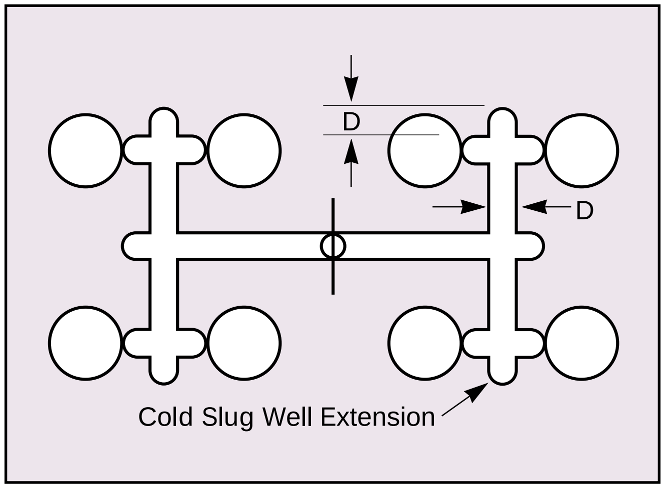


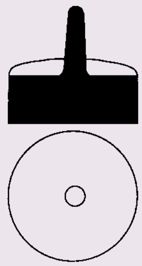
Figure 8.1 Balanced Runner and Cavity Layout

For more information on runnerless molding, contact your Ticona technical polymers representative or call Product Information Services at 1-800-833-4882.

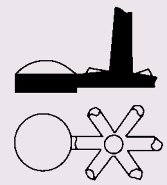
Gates

Various types of gates used in injection molds are shown in Figures 8.2A (page 8-3) and 8.2B (page 8-4).

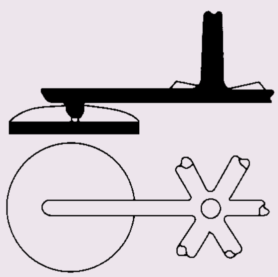
Gate location should be selected carefully to minimize possible part distortion or adverse effects on part dimensions due to anisotropic shrinkage (see "Mold Shrinkage", page 8-5). For best results, the gate should be located so as to achieve balanced flow in all directions, and minimum flow length from the gate to the extremities of the part. Where this is not possible, the gate should be located so that the flow direction is along the axis of the most critical dimension, since the mold shrinkage is considerably less in the direction of flow, particularly in glass fiber reinforced grades.



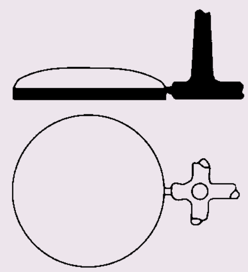
SPRUE: A simple design for single cavity molds and symmetry on circular shapes.
Suitable for thick sections.



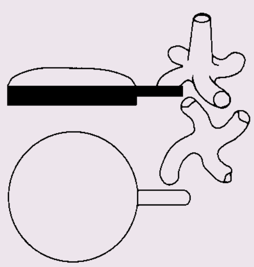
SIDE or EDGE: A simple design for multicavity molds. Suitable for medium and thick sections.



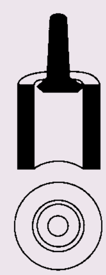
PIN (3 plate tool): Used to minimize finishing where edge gating is undesirable and for automatic degating. Only suitable for thin sections.



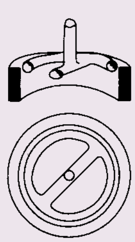
RESTRICTED or PIN: Provides simple degating and finishing. Only suitable for thin sections.



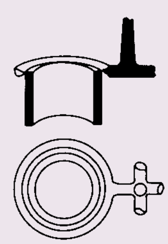
TAB: Used to stop jetting when other means are not available and when a restricted gate is desired. Also enables area of greatest strain to be removed from the molding.



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.

Figure 8.2A Various Gate Types Used in Injection Molds

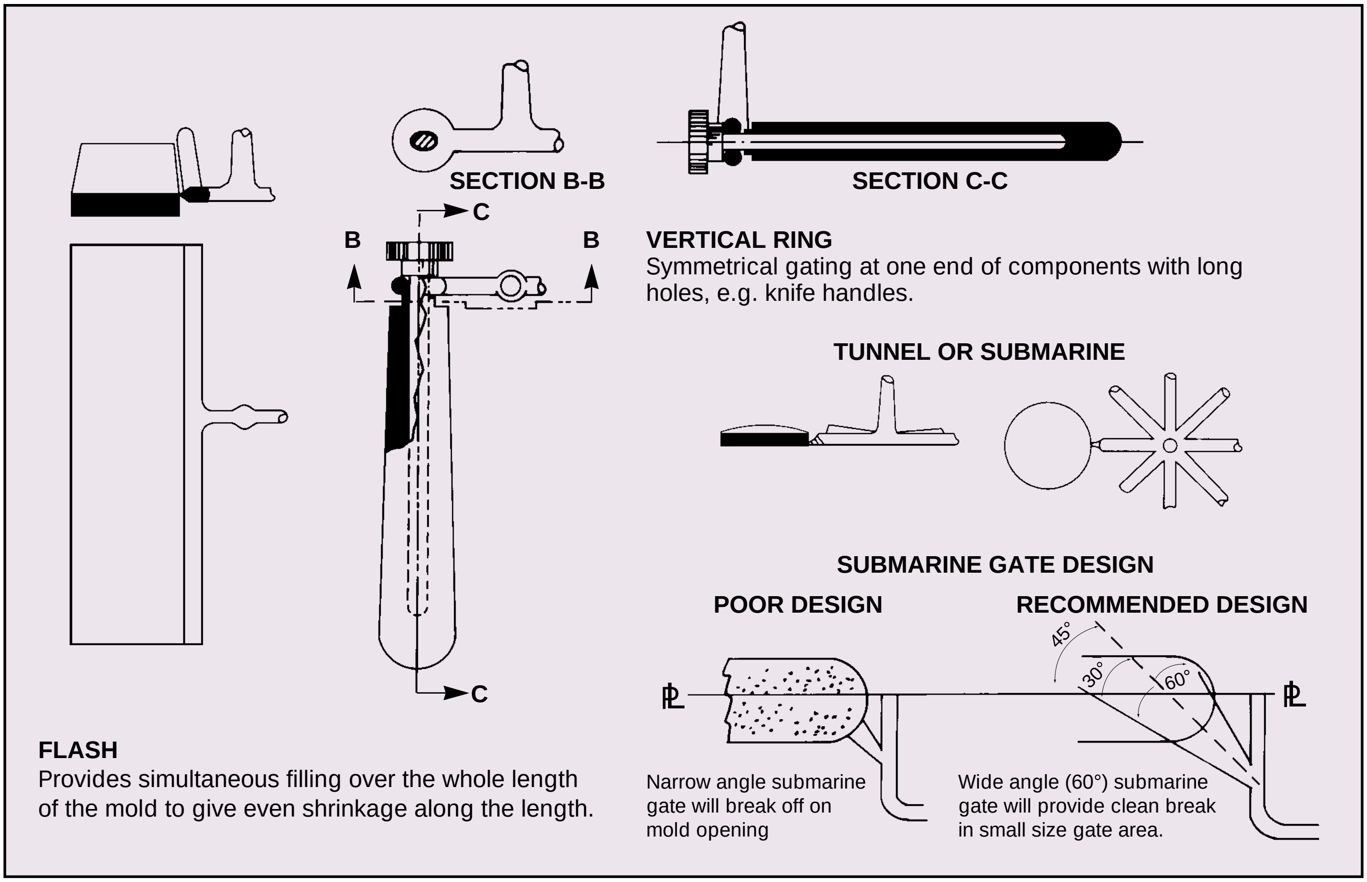


Figure 8.2B Various Gate Types Used in Injection Molds

To minimize breakage and reduction in length of the glass fibers in the reinforced grades, it is desirable to gate the part in a thick rather than a thin-walled section, and to incorporate radii where the runner joins the gate. This is illustrated in Figure 8.3.

Gate size recommendations, keyed to part thickness, are given in Tables 8.2 and 8.3 (page 8- 6). As a general rule, the gate should be one part thickness wide and 2/3 part thickness deep.

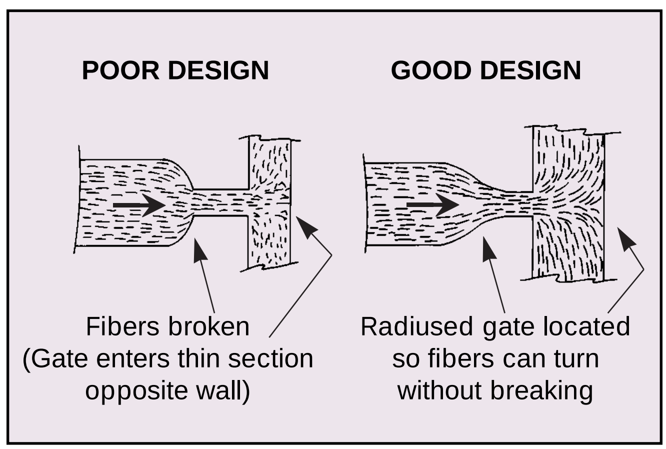


Figure 8.3 Gate and Mold Design Affect Part Strength

Table 8.2 Size Recommendations, Rectangular Edge Gate

Part Thickness, mm (in)	Gate Depth, mm (in)	Gate Width, mm (in)	Land Length, mm (in)
Less than 0.8 (0.030)	To 0.5 (0.020)	To 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 - 0.0900	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 8.3 Size Recommendation, Direct Gate (From Secondary Sprue in 3-Plate Mold)

Part Thickness, mm (in)	Gate Diameter, mm (in)	Land Length, mm (in)
Less than 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)

Venting

Because of the rapid mold filling qualities of polyesters, adequate mold venting is necessary to preclude the burning of material from compressed air. Vents should be located at the edge of the cavity furthest from the gate. The suggested vent size is 0.025 mm (0-001 in.) deep x 3.2 mm (0.125 in.) wide. These vents should be cut in the mold parting line from the edge of the cavity to the outside of the mold. Vents should be deepened, beginning 3.2 mm (0.125 in.) from the cavity. Venting is particularly critical at knit-lines and the last segment of the cavity to fill.

Mold Cooling

Productivity and part quality are directly influenced by proper mold cooling. Polyesters, when cooled below the melting point, solidify rapidly with the potential for achieving fast molding cycles. This requires a well designed mold cooling system that provides a uniform mold temperature with cooling channels near thicker part sections, and (when possible) directly in mold inserts and cores. For proper mold temperature control, a separate temperature controller for core and cavity is recommended. Temperature controls capable of reaching 121°C (250°F) will provide sufficient flexibility for most molding applications.

Melt Flow

Polyester is extremely fluid in the melt state and therefore flows well in a mold. However, rapid crystallization imposes limitations on how far the resin will flow in filling a mold. Among the process variables that influence flow are melt temperature, mold temperature and injection pressure. Wall thickness also influences resin flow. Thicker sections allow for longer flow lengths than thinner sections. Figure 8.4 shows the influence of wall thickness on flow.

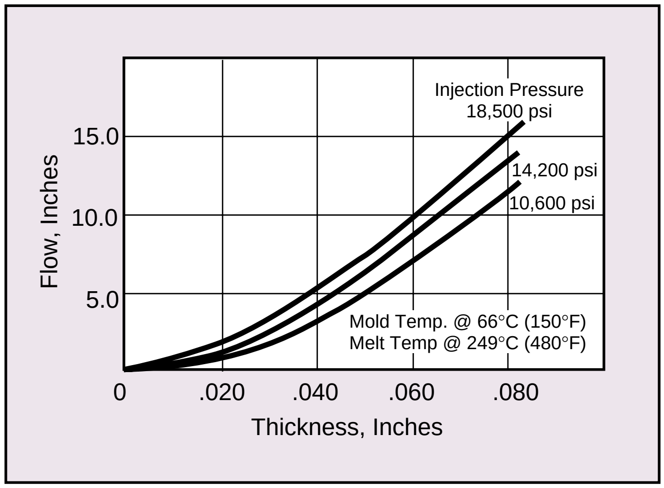


Figure 8.4 Flow Versus Wall Thickness for Celanex 3300

Mold Shrinkage

To accurately design molds, **it is strongly recommended that the mold/design engineer determine shrinkage of the actual part by using prototype tooling before making the final tool.**

Measurements of the material to be used should be made on prototype parts having the same geometry as the final part. Shrink measurements on a spectrum of molding conditions should be included to define the range of variations. Note that changes in gating, weld lines, mold cooling, etc. will change shrinkage of the final part versus the prototype part.

Contact your Ticona technical polymers representative or call Product Information Services at 1-800-833-4882 for further information on part shrinkage before molds are sized to final dimensions.

Note: In designing molds, extreme care must be exercised when using shrinkage data from ISO or ASTM test specimens. These data should be used only as a guide for plastic material property comparisons. See Tables 8.4 through 8.7.

Table 8.4 Shrinkage Data* for Celanex® Thermoplastic Polyester

Grades	In/In Flow Direction	(%)
Unreinforced, General Purpose		
All Grades	0.018 -0.020	1.8 - 2.0
Unreinforced, Flame Retardant		
2016	0.025 - 0.030	2.5 - 3.0
Glass Reinforced, General Purpose		
3200	0.005 - 0.007	0.5 - 0.7
3300, 3400	0.003 - 0.005	0.3 - 0.5
Glass Reinforced, Flame Retardant		
3116	0.010 - 0.014	1.0 - 1.4
3216	0.004 - 0.006	0.4 - 0.6
3226	0.003 - 0.006	0.3 - 0.6
3316	0.003 - 0.005	0.3 - 0.5
Glass Reinforced, Improved Impact		
4300	0.003 - 0.005	0.3 - 0.5
Glass/Mineral Reinforced, Low Warp		
J600	0.004 - 0.006	0.4 - 0.6
6407, 6500	0.002 - 0.005	0.2 - 0.5
Glass/Mineral Reinforced, Low Warp, Flame Retardant		
7305, 7316	0.003 - 0.005	0.3 - 0.5

Table 8.5 Shrinkage Data* for Vandar® Thermoplastic Polyester Alloys

Grades	In/In Flow (Transverse) Direction	(%)
Unreinforced, Improved Impact		
2100, 2500, 4602Z	0.017 - 0.022	1.7 - 2.2
Unreinforced Flame Retardant		
8000	0.025 - 0.028	2.5 - 2.8
Unreinforced, Cold Temperature Impact		
8929	0.015 - 0.020	1.5 - 2.0
9114, 9116	0.011 - 0.016	1.1 - 1.6
Glass Reinforced, Improved Impact		
4361	0.002 - 0.005	0.2 - 0.5
4612R	0.006 - 0.008	0.6 - 0.8
4632Z	0.004 - 0.006	0.4 - 0.6
4662Z	0.003 - 0.005	0.3 - 0.5
Mineral Reinforced		
2122	0.013 - 0.015	1.3 - 1.5

**Data obtained from 0.125 inch thick laboratory test specimens.*

Table 8.6 Shrinkage Data* for Impet® Thermoplastic Polyester

Grades	In/In Flow Direction	(%)
Glass Reinforced, General Purpose		
320R	0.004 - 0.007	0.4 - 0.7
330R	0.001 - 0.003	0.1 - 0.3
340R	0.001 - 0.002	0.1 - 0.2
Glass/Mineral Reinforced, Low Warp		
610R	0.005 - 0.008	0.5 - 0.8
630R	0.003 - 0.005	0.3 - 0.5
830R	0.001 - 0.003	0.1 - 0.3

Table 8.7 Shrinkage Data* for Riteflex Thermoplastic Polyester Elastomers

Grades	In/In Flow Direction	(%)
Unreinforced, Specialty Polymers		
640	0.009 - 0.011	0.9 - 1.1
655	0.014 - 0.016	1.4 - 1.6
677	0.018 - 0.022	1.8 - 2.2

**Data obtained from 0.125 inch thick laboratory test specimens.*

Molding Process and Equipment

To consistently and efficiently produce high quality parts, it is essential to understand resin storage and drying requirements, regrind to-virgin resin ratios, the molding process and associated equipment. These topics are covered in the publication titled Celanex, Vandar, Impet, and Riteflex Thermoplastic Polyesters - Processing and Troubleshooting Guide (PE-6).

Assembly

Introduction

Components molded of Celanex®, Vandar®, Impet®, and Riteflex® thermoplastic polyester are easily assembled using conventional plastic joining techniques. Some of the more common techniques are discussed in this chapter.

In selecting the method for joining components, consideration must be given to:

- Specific part design to avoid surface damage of male or female molded parts during the assembly process which could reduce mechanical properties such as impact strength.
- Environmental conditions that the assembled part will be exposed to during its useful life.

Mechanical Fastening Techniques

Snap-fit Joints - A common method of assembling two plastic parts is the snap-fit, a form-fitting joint that permits great design flexibility. All of the various types basically involve a projection (such as a barb) molded on one part which engages a corresponding hole or undercut on the other. During assembly, the parts are elastically deformed and tend to return to their original shape, which provides the holding force for the two parts. Snap-fits are often designed to be non-detachable, and this type of joint can withstand a high degree of permanent loading. Designing a snap-fit for repeated assembly and disassembly is also feasible. Not all snap-fit joints and/or recommendations will work for the softer Riteflex and Vandar polyesters.

The three common types of snap-fit joints are “Barbed leg”, “Cylindrical”, and “Ball and socket”.

Barbed legs are spring elements supported on one or both sides, and are sometimes pressed through holes in the mating part. The hole can be rectangular, circular or slotted. The cross section of the barbed leg is usually rectangular, but shapes based on round cross sections are also used. Here, the originally cylindrical snap-fit is divided by one or several slots to reduce assembly force.

In designing a barbed leg, care should be taken to prevent over stressing at the most vulnerable point of support. The radius “r” should be as large as possible, as shown in Figure 9.1.

Cylindrical snap-fits (Figure 9.2) have a molded cylindrical part with a lip or thick section, which engages a corresponding hole or groove in the mating part. The difference between the largest diameter of the shaft “DG” and the smallest diameter of the hub “DK” is the interference depth “H”:

$$H = D_G - D_K$$

The parts are deformed by the amount of this interference depth during assembly.

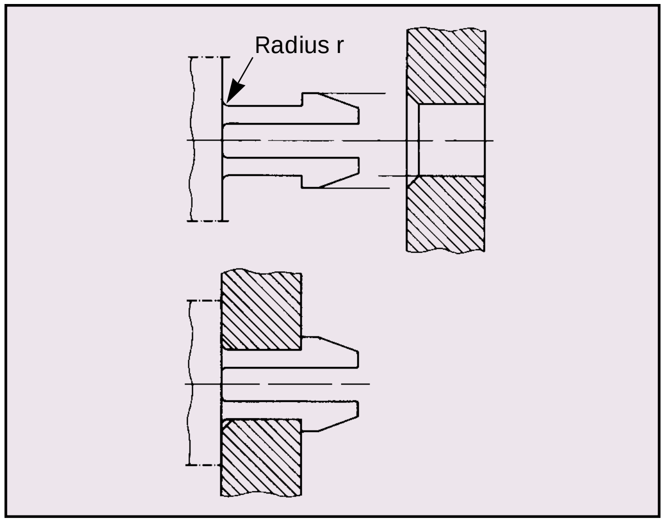


Figure 9.1 Barbed Leg Snap-fit

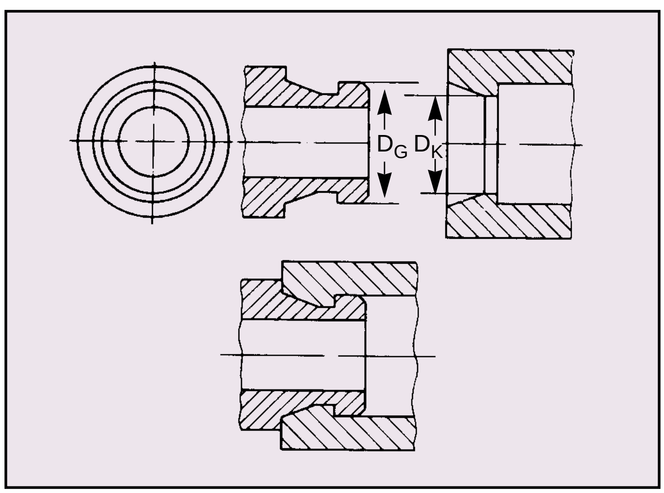


Figure 9.2 Cylindrical Snap-fit

Ball and socket snap-fits (Figure 9.3) are mainly used as motion transmitting joints. A ball section engages in a corresponding socket; the interference depth "H" is the difference between the ball diameter "D_G" and the socket opening diameter "D_K".

With cylindrical and ball and socket snap-fits, the maximum permissible interference depth "H_{max}" is obtained from the maximum permissible elongation using the relationship:

$$\mathbf{H_{max} = \frac{E_{max}}{100} \times D_G}$$

where E_{max} is the maximum elongation, %

Independent of the type of snap-fit, there is a linear relation between the undercut depth and the hub elongation; i.e. the maximum permissible undercut depth is limited by the maximum specified allowable elongation. The load-carrying capacity of snap-fits depends on the elastic modulus and coefficient of friction. It can be matched to the requirements of the joint by adjusting the undercut depth and the assembly or retaining angle.

Strain Limits, Snap-fit Applications - Because a snap-fit assembly tends to put flexural loads on parts, it is most appropriate to use flexural strain data to design snap-fits. However, tensile strain data can be used if flexural strain data is not available.

The following may not apply to the softer Riteflex and Vandar polyesters.

Maximum Allowable Strain Based on Flexural Data - The ISO flexural tests is generally conducted to a maximum strain of 5.5%, so the actual break value is not known if it is greater than 5.5%. If the reported strain at break is less than 5.5, then the maximum allowable strain should be 50% of the Strain at Break. If the test was stopped at 5.5%, then the tensile strain data should be used.

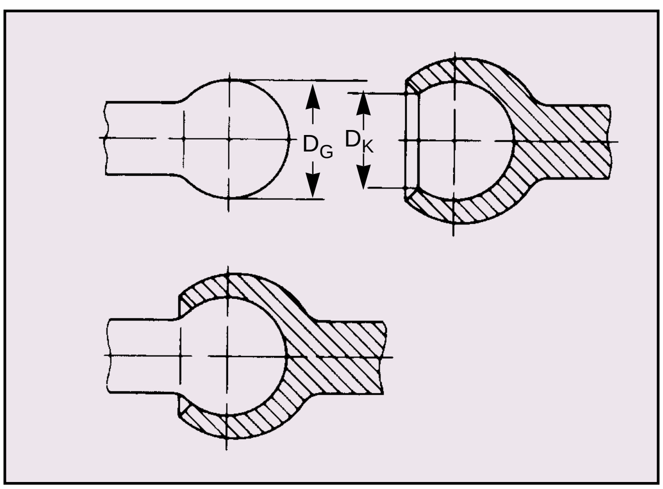


Figure 9.3 Ball and Socket Snap-fit

Maximum Allowable Strain Based on Tensile Data - For materials with a clear yield, the allowable strain is:

- 70% of yield strain - single snap application
- 40% of yield strain - repeated snap applications

For low elongation materials that break without a clear yield point, the allowable strain is:

- 50% of the strain at break - single snap applications
- 30% of the strain at break - repeated snap applications

Many of the softer grades of Riteflex and Vandar polyester will not show a yield point and the above recommendations will not apply.

Strain data on Polyester can be obtained by referring to the appropriate brochure listed below or by calling Product Information Services at 1-800-833-4882.

- Celanex® Thermoplastic Polyester - Short Term Properties (CX-4)
- Vandar® Thermoplastic Alloys - Short Term Properties (VN-4)
- Impet® Thermoplastic Polyester - Short Term Properties (IP-4)
- Riteflex® Thermoplastic Polyester Elastomer - Short Term Properties (RF-4)

Snap-on/Snap-in Fits - Another type of snap-fit assembly is called a snap-on or snap-in fit. It can sometimes be molded into the part, and is most often used with rounded parts. Its advantage is that in operation, some or all of the entire part flexes, but the total deflection is very small and is well below the yield strain value. Figure 9.4 illustrates this type of snap-fit configuration.

Snap-ons are also amenable to release of the assembled part by using a tool to provide a releasing force. This is required when it may be necessary to have repeated servicing of the operating equipment within the plastic assembly.

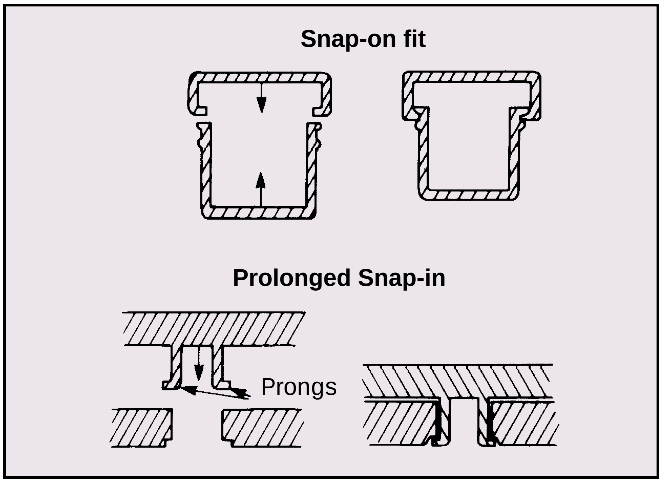


Figure 9.4 Snap-on/Snap-in Fits

Molded-In Inserts - Metal inserts of steel, brass, and aluminum can be successfully molded into polyester resins using the following recommendations:

- Use an insert with a coarse knurl for maximum holding power. Make sure the knurl ends below the surface of the plastic.
- Radius all sharp corners on the insert. Use tumbling or grit blasting to break sharp corners on the knurl.
- Use Inserts with blind internal holes as opposed to through holes. At the closed end, use a generous radius or spherical shape.
- Project the open end of the insert above the surface of the molding.

Threads - Standard systems can be used to assemble polyester parts. See Chapter 7 for designing threaded connections.

Self-Tapping Screws - Using self-tapping screws is an effective and relatively inexpensive method of assembling components. Only a pilot hole is needed which can be drilled or molded in the components to be joined. See Table 9.1 for recommended optimum pilot hole diameters for various screw sizes for Celanex polyesters.

Note: Recommended pilot hole size must be maintained with a tolerance of ± 0.025 mm (0.001 in.) for optimum fastening strength.

Both thread cutting and thread forming screw designs are widely used. Combinations of both designs are very popular because they have excellent holding power and minimize stresses produced during thread forming. Table 9.1 shows driving torque, stripping torque, and pull out strength values for various fasteners. Note that thread forming screws give somewhat higher stripping torques and pull-out strengths.

Driving torque values indicate the torque necessary to drive screws into pilot holes. Stripping torque values indicate the tightening torques that will strip threads formed by the self-tapping screws. In many applications, a low driving torque with a substantial drive/strip ratio is of primary importance. Although the driving torque values obtained from polyester are comparable to those necessary for fastening other thermoplastic materials, the stripping torque values for polyester are considerably higher (sometimes by a factor of 2 or 3) than the values for other plastics.

The higher the torque used to tighten self-tapping screws (“seating torque”), the greater the clamping force which will be exerted between the components assembled. Screw manufacturers generally recommend a seating torque 1/2 to 3/4 of the stripping torque.

In some other applications, holding strength is the primary consideration. The driving and stripping torques may be of minor importance, although the drive torque must not be excessive and the drive/strip ratio must be reasonable (about 3:1). Holding strength is measured by pull out force (the force necessary to pull out, without turning the self-tapping screws from the polyester parts).

In still other applications, loosening from vibration is important. Independent laboratory tests show that polyester components joined with self-tapping screws have excellent resistance to vibration by the military standard used for ground vehicles.

Table 9.1 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)

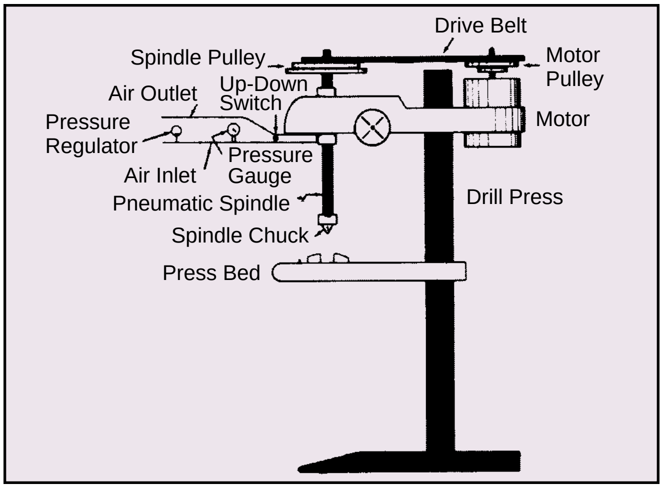


Figure 9.5 Simple Spin Welding Apparatus

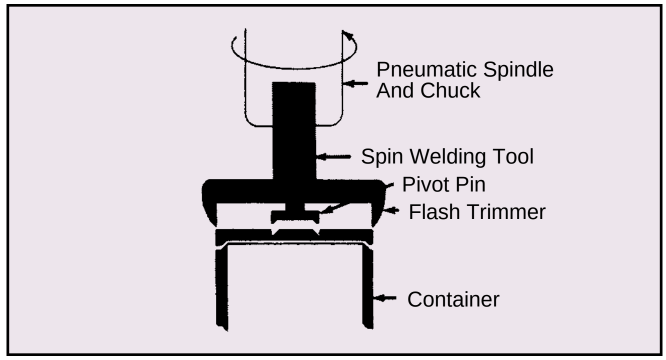


Figure 9.6 Pivot Tool with Flash Trimmer

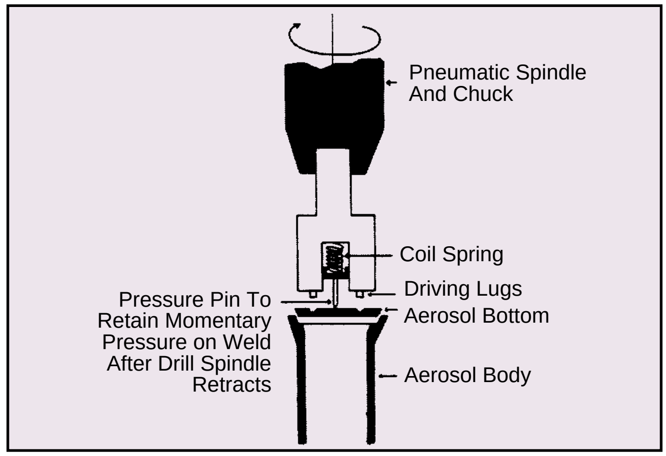


Figure 9.7 Driving Tools for Spin Welding

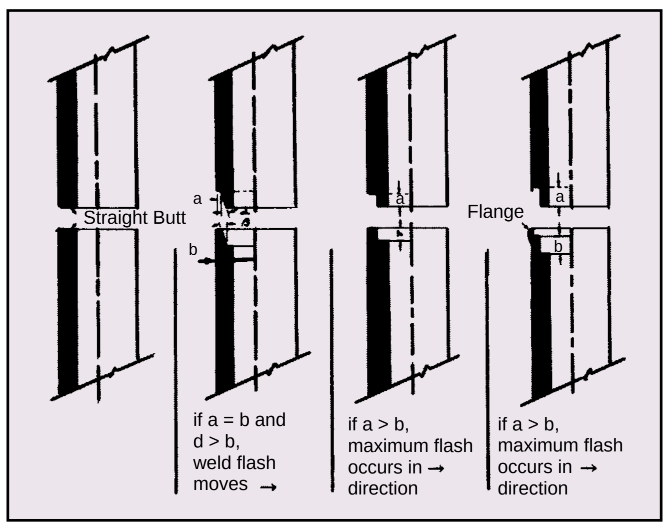


Figure 9.8 Typical Joint Configurations for Spin Welding (Hollow Members)

Welding Techniques

Spin Welding - In spin welding, one piece is rotated in contact with the mating stationary piece to produce a frictional melt. The equipment required for spin welding can be very simple (see Figure 9.5) or elaborate depending upon production requirements. The stationary piece should be secured in position with the weld area in the same axis as the mating part, and at a level that will allow the mating part to be brought down firmly into contact. Although all spin welds are round, the parts themselves may have non-circular shapes.

The raising and lowering mechanism should be checked to assure proper alignment. When mating surfaces are rotated in contact with sufficient pressure, melt is achieved in less than one second. One of the skills required for strong joints in spin welding is to quickly stop and hold slightly increased pressure on the pieces immediately after sufficient melt is attained. Spinning too long can cause excessive melting, and the joint area may retain unsightly markings from flash. Strength of the welded piece is influenced by the rotational speed and pressure used and the subsequent clamping pressure maintained after stopping. Therefore, it is recommended that weldings made under a variety of conditions be tested to determine optimum conditions for production welding. Driving tools for rotating parts while spin welding are shown in Figures 9.6 and 9.7.

Spin welded joints can have straight 90° mating surfaces, or surfaces that are angled, molded in a V-shape, or flanged. Angled joints, shown in Figure 9.8, can retain flash and provide some added weld surface. When the mating halves have a closely toleranced flange, it too can produce friction during rotation and become an integral part of the weld. Joint configurations shown in Figure 9.8 are representative of many types used. Although good strength can be achieved with those shown, many others could do equally well.

Thermal Fusion Welding - Originally known as hot plate welding because of the equipment used, thermal fusion welding is suitable for joining parts ranging from some of the smallest to the largest moldings produced. All grades of polyester resins are suitable for bonding by this technique and strengths of 70 - 100% of the resin strength can be expected with unfilled grades. Due to the limited mixing of glass fibers across the joint, the weld strength of reinforced grades generally will not exceed that of the unfilled base resin.

The basic concept of thermal fusion welding involves placing two molded thermoplastic parts in contact with a heated surface until melting occurs. The molded parts are then rapidly brought in contact with each other and held securely in place until sufficiently cooled and resolidified.

An ordinary laboratory hot plate may be used when a limited number of parts are involved. For production purposes, automated equipment is recommended. The two parts to be joined are placed in separate fixtures aligned so the joint surfaces may be mechanically brought together (see Figure 9.9). A heated platen is positioned between the parts which are subsequently moved forward until contact is made. After sufficient time elapses to allow melting of the surfaces to occur, the parts are slightly withdrawn, the platen is removed, and the moldings are brought together under a controlled pressure. When the parts have resolidified, the fixtures are opened and the assembly is removed.

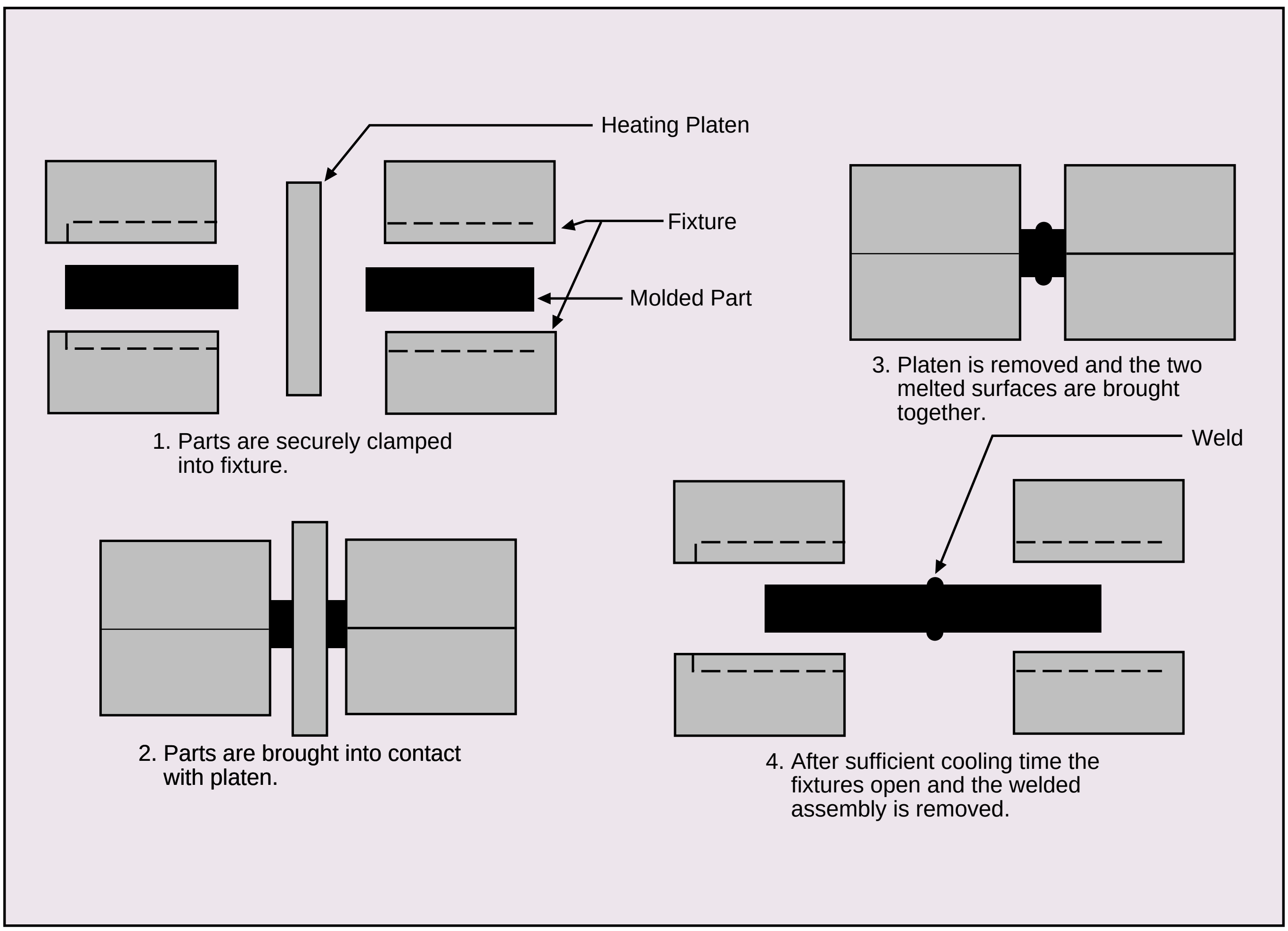


Figure 9.9 Thermal Fusion Welding

Thermal Fusion Holding Fixtures - Multi-cavity fixtures are commonly used for the rapid welding of large numbers of parts.

To achieve optimum tolerance control and weld strength, the fixtures must properly locate and firmly secure the moldings. Pneumatically or hydraulically operated clamping mechanisms are used which can be actuated by limit switches or electrical timers as the machine moves through its welding operation.

Thermal fusion welding involves displacing material as the weld is formed which generates flash. Controlling this flash may be accomplished by concealment through joint design or by removing the flash using a special die built onto the fixture. Dies have been designed that are capable of trimming flash automatically as an additional step to the welding sequence. Assistance in fixture and die design is available from most suppliers of thermal fusion welding equipment or from your Ticona representative.

Thermal Fusion Part/Joint Design - Ordinary butt joints are most suitable for thermal fusion welding. Most variations include a method to control the resulting flash (see Figure 9.10). Usually, It is possible to design a joint that allows the assembly to be placed in service without trimming.

The amount of material to be displaced by the weld must be determined during the initial stages of part design. Sufficient volume for collection of flash should be included when a flash trap is used, and allowances made to achieve the desired dimensions of the final assembly. Approximately 0.5 mm (0.020 in.) per side is generally a suitable displacement.

Good welding practice suggests that the joint surfaces be flat, clean of any foreign material and dry.

Thermal Fusion Welding Parameters - The achievement of optimum welding cycle times depends on rapidly heating the resin. While the use of higher platen temperatures will heat the material more rapidly than lower temperatures, it is the material's thermal conductivity which primarily controls the heating time required. Care must be taken that the material is melted to a sufficient depth while not being degraded at the contact surface. Typical platen temperature for Celanex polyesters are provided in Table 9.2.

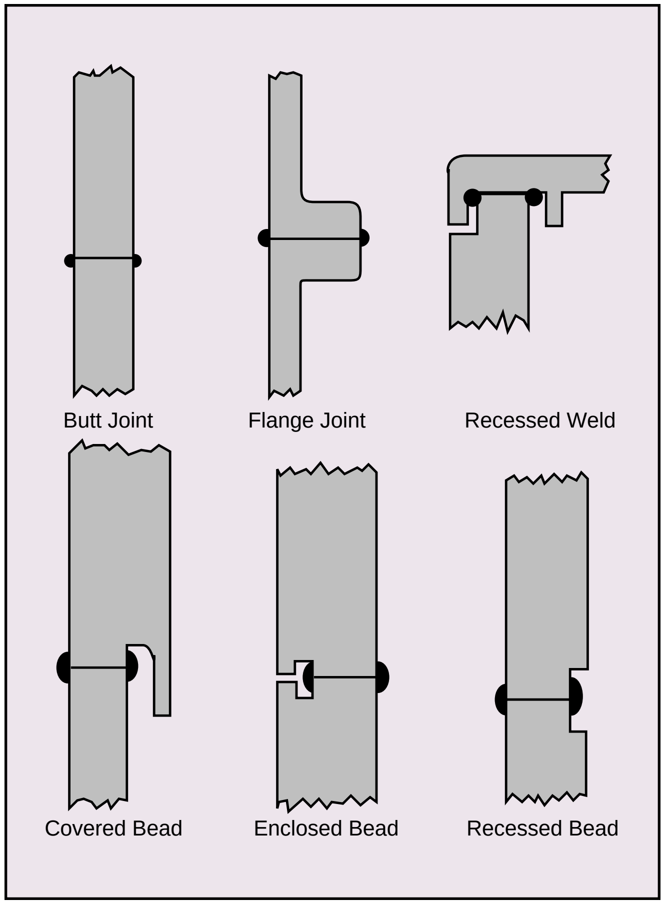


Figure 9.10 Typical Thermal Fusion Weld Joint Designs

Table 9.2 Typical Welding Conditions for Celanex Polyesters and Impet Polyesters

Platen (Hot Plate) Temperature °C (°F)	Heat Time (seconds)	Cool Time (seconds)
288-338 (540-640)	12 - 30	6 - 12

Parts to be welded should be placed in contact with the heated platen under light pressure. Usually a pressure of 14 - 34 kPa (2 - 5 psi) measured across the joint area is adequate. Although excessive pressure will not accelerate melting, it may cause molten polymer to flow laterally outward, resulting in limited heat penetration. Welding equipment should be adjusted to allow approximately 0.3 mm (0.010 in.) of the resin to be displaced during heating before movement is prevented by a positive stop. See Figure 9.11.

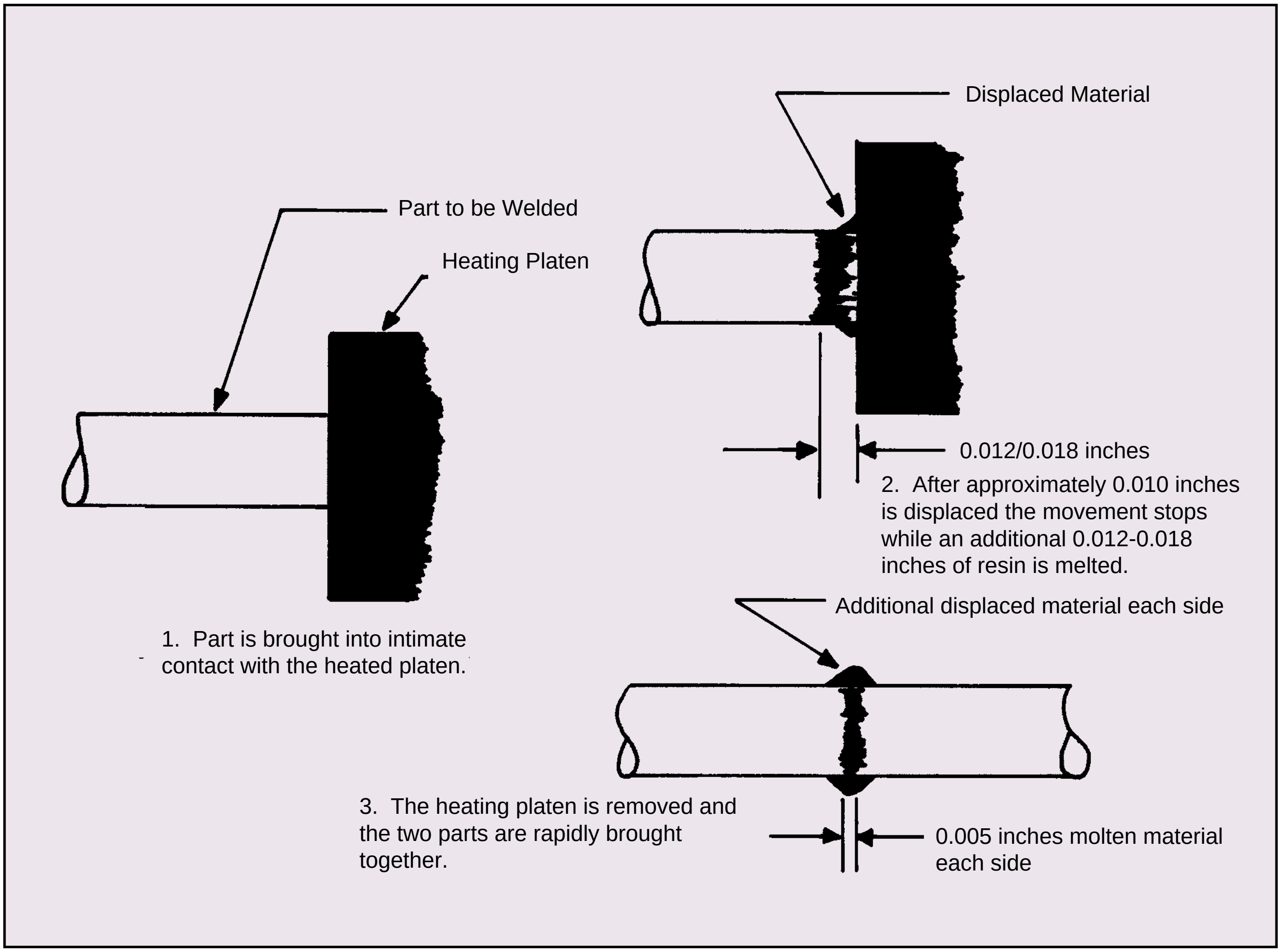


Figure 9.11 Heating The Plastic Resin for Welding

This displacement assures intimate contact with the platen for uniform heat transfer. The moldings then remain in contact with the platen until an additional 0.3 - 0.5 mm (0.012 - 0.018 in.) has melted. It is important to obtain melting to this depth to insure that only properly melted resin will be joined to form the weld. At that time, the parts are pulled back from the platen, the platen is removed, and the moldings are brought together as rapidly as possible.

The importance of rapid movement can not be overemphasized. Polyester resin is a rapidly crystallizing material with a relatively sharp melting point. Optimum weld strengths will not be obtained if surface temperature drops below the melt point prior to contact.

Because of this correlation between weld strength and time between heating platen and weld contact, care should be taken to insure that the distances moved and times required are as short as possible. The holding pressure should be adjusted to maintain the parts in secure contact without causing an excessive amount of the molten resin to flow. Excessive pressure could displace molten material and cause unmelted resin to remain in contact, resulting in poor adhesion across the joint as well as the generation of heavy flash.

Under optimum conditions, about 2/3 of the molten resin should flow from the joint (i.e. 0.3 mm [0.010 in.] when plasticized to a depth of 0.4 mm [0.015 in.]). This will provide a suitable layer of melt to form a bond. A holding pressure of 103 - 241 kPa (15 - 35 psi) on the joint area is generally acceptable.

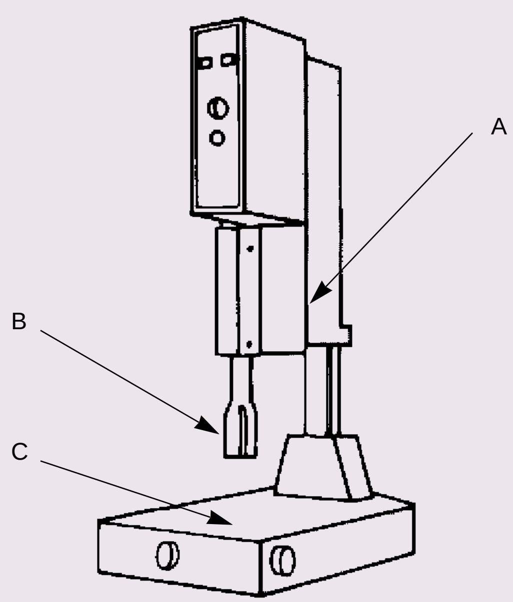
Ultrasonic Welding - Ultrasonic welding is an economical method for joining parts with similar or equivalent melting characteristics and chemical compatibility. This technique is very rapid and can be fully automated. Figure 9.12 shows typical ultrasonic welding equipment

In ultrasonic welding, electrical energy is converted into vibrational energy of approximately 20 kHz (most widely used) or 40 kHz (used for small, delicate parts). The energy is then amplified and transmitted to the mating part in contact with the machine. The vibrating part rubs against the stationary second part and quickly melts the surface by frictional heat. Bonding is virtually instantaneous, and the bond strength is close to 100% of the tensile strength of unfilled polyester, especially when a shear joint (see Figure 9.13) is used. With this type of joint, welding is accomplished by melting the small initial contact area and then continuing the melting process with a controlled interface along the vertical walls as the parts telescope together. This creates a strong, structural seal as the molten interface completely fills the empty spaces between the two mating parts.

Once proper operating conditions have been established, virtually any grade of polyester can be ultrasonically welded. Glass reinforced grades, however, will only possess the bonding strength of the unreinforced grades since the glass does not extend through the mating surface of the two parts.

To obtain acceptable, high quality welded joints, the following design factors must be considered:

- Initial contact area between the mating surfaces should be small to concentrate and decrease total time and energy required. In some cases, the ultrasonic energy must be applied before the parts touch each other to prevent 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 on a single plane.
- Mating parts must be perfectly aligned by using support fixtures and/or pins and sockets, tongues and grooves, etc. Do not depend on the vibrating horn of the ultrasonic machine to hold parts in place.
- Mating surfaces must be clean and dry.



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

Figure 9.12 Typical Ultrasonic Welding Equipment

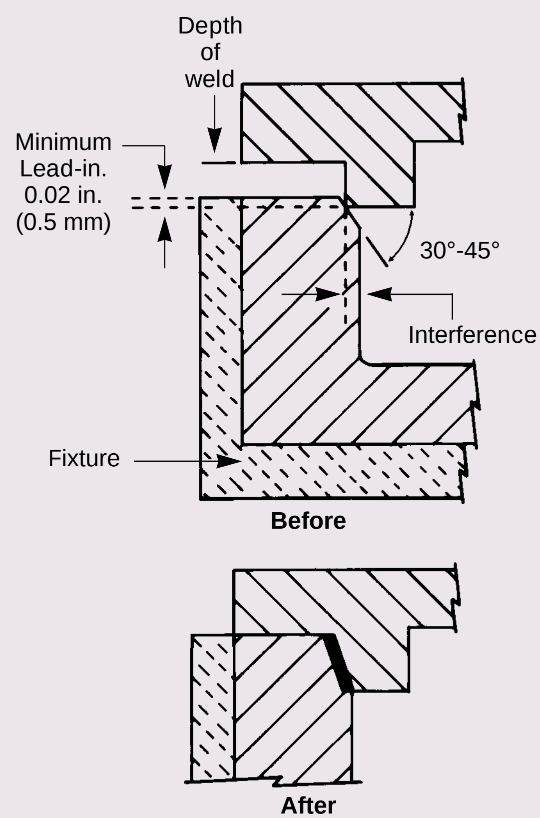


Figure 9.13 Recommended Shear Joint Configuration

Table 9.3 Interference Guidelines for Polyester Shear Joints

Maximum Part Dimension mm (in)	Interference Per Side mm (in)	Part Dimension Tolerance mm (in)
Less Than 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)
Greater Than 35 (1.50)	0.4 - 0.5 (0.016 - 0.020)	± 0.075 (0.003)

As with other joining and machining techniques, molded parts with sharp corners should be generously radiused to avoid fracturing or causing any other damage during ultrasonic welding. Holes and voids such as ports or other openings in the mating areas should be avoided because they can create an interruption in the transmission of ultrasonic energy, and compromise the integrity of the weld. Similarly, bosses, tabs or other projecting surfaces on the interior or exterior of the part should be well radiused to avoid fracturing due to mechanical vibration.

“Bowing” (distortion) of flat, circular parts sometimes occurs during ultrasonic welding. This can usually be eliminated by increasing wall thickness and/or adding internal support ribs. Minimizing ultrasonic weld time is also helpful.

Design and quality control of the parts, proper placement of the welding amplifier (“horn”) and maintenance of equipment settings are all critical to obtaining consistent and reproducible adhesion.

Adequate ventilation should be provided at each workstation to remove all fumes during the welding operation.

Table 9.3 gives interference guidelines for shear joints using polyester. These guidelines were developed for PBT and may or may not apply to other polyesters.

Other Ultrasonic Techniques - Other techniques, illustrated in Figure 9.14, are used for various special operations in part assembly.

Ultrasonic staking uses the controlled melting and reforming of a plastic stud to lock two components of an assembly in place. The stud in the first component protrudes through a hole in the mating part. Ultrasonic energy melts the stud which then fills the hole volume to produce a molten head, which upon cooling locks the two components in place. Some of the advantages include:

- Very short cycle times.
- Tight assemblies.
- Ability to perform multiple staking with one machine.
- Elimination of mechanical assembly such as with screws and rivets.
- Ability to ultrasonically drive metal inserts into plastic parts for subsequent mechanical assembly.

Ultrasonic spot welding can be used where large, complex parts need to be joined in specific locations, and a continuous joint or weld is not feasible or necessary.

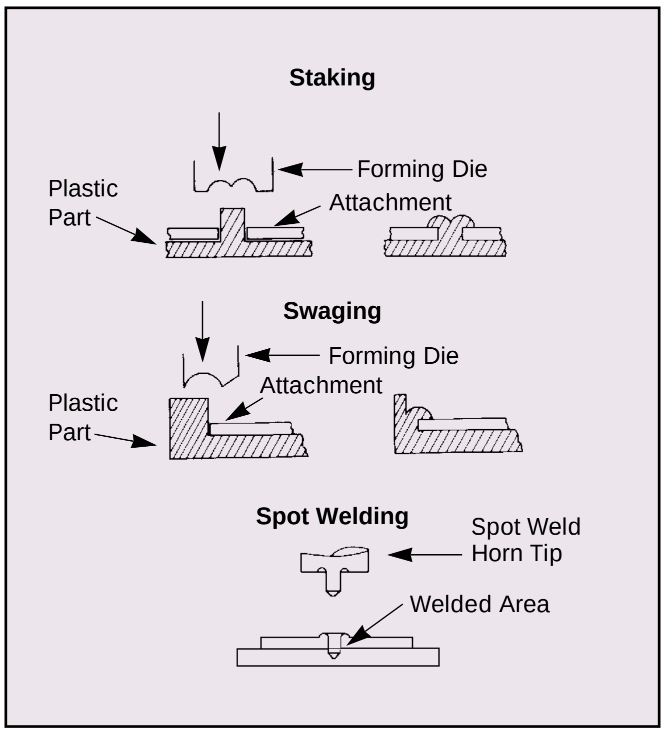


Figure 9.14 Ultrasonic Staking, Swaging and Spot Welding

Adhesive Bonding

Parts molded of polyester resin can be bonded to each other or to dissimilar materials using commercially available adhesives. Most commonly used adhesives for polyester resins are those based on epoxy resins, polyurethanes or cyanoacrylates. Adhesive manufacturers tailor their formulations to conform to a wide range of performance standards. When selecting an adhesive, consideration must be given to mechanical performance of the assembly as well as chemical and temperature exposure in the end-use environment.

Best bond strengths are obtained by sanding the part mating surfaces and cleaning them with a solvent (such as acetone) before bonding. Although high viscosity adhesives are sometimes used as gap-fillers, good bonds normally require closely mated surfaces.

Recommended adhesives for bonding polyester to polyester are provided in Table 9.4.

Note: Before bonding polyester parts with any of the recommended adhesives, read and follow the instructions and safety precautions provided by the adhesive manufacturers.

Table 9.4 Recommended Adhesives for Bonding Polyester Resins

Adhesives	Manufacturer	Manufacturer's Recommendations
Cyanoacrylate - Permabond 102	Permabond International Corporation 480 South Dean Street Englewood, NJ 07631 Tel: 800-653-6523 www.permabond.com	Use for bonding Celanex, Vandar, and Impet products.
Methacrylate - Plexus™ MA330	ITW Plexus 30 Endicott Street Danvers, MA 01923 Tel: 978-777-1100 www.itwplexus.com	Use for bonding Vandar products. Do not use for bonding Celanex or Impet products.
Epoxy - Araldite™ 2011 and Polyurethane - 2042 (fast cure)	Ciba Specialty Chemicals 31601 Research Park Drive Madison Heights, MI 48071 Tel: 800-875-1363 www.cibasc.com	
Polyurethane - UR2139	H.B. Fuller 3530 Lexington Avenue North St. Paul, MN 55126 Tel: 888-423-8553 or 651-236-5900 www.hbfuller.com	
Cyanoacrylate - Prism 401 and Primer: 770	Loctite 705 North Mountain Road Newington, CT 06111 Tel: 800-562-8483 or 860-571-5100 www.loctite.com	

Note: Celanex 2000 and 3300, Vandar 9116, and Impet 830R were bonded to themselves and tested by the Permabond International Corporation and ITW Plexus.

Machining and Surface Treatment

Introduction

This chapter provides guidelines for machining and surface treating parts made of Celanex®, Vandar®, Impet®, and Riteflex® thermoplastic polyesters.

Machining

Machining can be accomplished on standard metal working equipment using tools and techniques common for other engineering thermoplastics.
To obtain the best machining results:

- Use only sharp tools.
- Provide adequate chip clearance.
- Support the work properly.
- Provide adequate cooling.
- Carbide tools may last longer when machining glass-filled materials.

Sawing - Cutting operations are accomplished using almost any type of saw (hand, circular, and band). To obtain good cutting results:

- Use sharp saw teeth having some degree of “set” to prevent the blade from binding.
- Use coarse teeth, such as 6 teeth per inch, rather than fine teeth.
- Use high speeds, such as 3000 - 4000 fpm, for smoother cuts. Avoid slower speeds.
- Use extra wide gullets for chip clearance.
- Use feed speeds of 10 - 15 fpm. Avoid slower feed speeds.
- When sawing sections thinner than 12.7 mm (0.5 in.), use a jet of compressed air directed at the cutting area to disperse the chips and help cool the blade. Also, backup the thin sections with chipboard or cardboard to eliminate any slight chipping that may occur.
- When sawing sections thicker than 12.7 mm (0.5 in.), use water directed at the cutting area to disperse the chips and help cool the blade.
- Using air, water or oil to cool the surface of parts made from the softer Riteflex and Vandar polyesters, will help prevent melting. Once a cut is started, it may need to be held open to prevent the material from moving back in towards the blade.

Drilling - Standard twist drills (118° point angle) and special plastic drills (100° angle) are suitable for drilling glass-reinforced grades. To obtain good drilling results:

- Use drill speeds of 1000-3000 rpm with a feed as fast as possible. Speeds in excess of 3000 rpm could melt the plastic.
- Firmly support the work during drilling.
- When drilling deep holes, frequently raise the drill every 6.4 mm (0.25 in.) of depth to clear the drill and hole of chips.
- Use a jet of compressed air directed into the hole to disperse chips and cool the drill. For production situations, a water soluble coolant may be helpful.
- It may be difficult to obtain good surface finishes or hold tolerances with the softer Riteflex and Vandar polyesters. The use of air, water or oil can improve the surface by keeping the temperature down. In order to hold the proper tolerance it may be necessary to use drill bits that are slightly smaller or larger than the desired hole size, depending on the speed used to drill the hole. The use of slightly oversized drill bits at lower speeds and slightly undersized drill bits at higher speeds may help. Test holes should be attempted at the intended speed to determine the size of the drill bit that will be needed.

Turning - Parts made of Celanex polyesters, Vandar polyesters, Impet polyesters, and Riteflex polyesters may be readily turned on a lathe. In general, feeds and speeds depend mostly on the nature of the cut and the finish desired. To obtain good turning results:

- For rough cuts, use speeds of 1500 - 2500 rpm with feeds of 50.8 cm (20 in.) per minute and higher.
- For finish cuts, use slower feeds to produce a fine finish.
- Keep cutting tools as sharp as possible.

- Provide enough clearance to prevent overheating the plastic.
- For Riteflex and the softer Vandar polyesters, the above speeds may need to be adjusted to prevent melting and to obtain a smoother surface. Rough cuts may produce long continuous strings, and leave burrs at fairly slow speeds. Faster speeds can produce smoother surfaces for finish cuts, but may need to be cooled with air, water or oil to prevent melting.

Milling - Standard helical type milling cutters are satisfactory for use on parts made of Celanex, Vandar, Impet, and Riteflex. To obtain good milling results:

- Keep the number of flutes as low as possible (2 - 4) to minimize overheating the plastic.
- Use cutter speeds of 2000 - 4000 rpm and feeds as fast as possible. Adjust feed rates as necessary to obtain the desired surface finish quality.
- Use a jet of compressed air to keep chips from clogging the flutes.

Filing - To obtain the best results in filing thermoplastic resins:

- Use the most coarse file consistent with the size of the surface and the finish required.
- Use milled curved-tooth files with coarse single cut or double cut shear-type teeth.
- Frequently brush the file to prevent clogging.

Rotary Power Filing - Rotary power files or burrs are very effective in removing unwanted resin material rapidly. To obtain good results:

- Use ground burrs (instead of hand cut rotary files) because they provide better chip clearance.
- Use high speed steel ground burrs (medium cut) or carbide burrs (medium or diamond cut).
- Use carbide burrs for high production rates. Carbide burrs are more economical because they last longer.
- Operate steel burrs at 800 - 1000 surface fpm and carbide burrs at around 2000 fpm.

Threading and Tapping - It may be impossible to tap the softer Riteflex Polyesters and Vandar polyesters.

Threads may be cut in Celanex and Impet thermoplastic polyester components on a lathe. Conventional taps and dies may also be used. To obtain satisfactory results:

- Use a special tap, designed for plastics, which has two flutes and a 6 - 8° rake. This offers some advantages in greater chip clearance.
- Use speeds that are half the surface speed recommended for drilling.

Surface Treatment

The surfaces of thermoplastic polyester parts may be processed in various ways for purposes that are decorative, functional, or a combination of both. These are briefly discussed in the following paragraphs. For detailed information on surface treatment and/or functional operations, call Product Information Services at 1-800-833-4882.

Dyeing - Several commercially available processes have been developed to color and decorate thermoplastic polyester resins. Known as diffusion and thermostatic dyeing, these processes can economically produce high-clarity, long lasting part decorations.

This technology is particularly well suited for applications where two-shot molding of characters (e.g. keys on typewriters and computer keyboards) is often employed. Such dyeing systems can be equally effective in replacing hot stamping, overlay, and silk screening techniques.

By taking advantage of the dry uptake of the polyester resin, significant depth of print can be achieved to improve “wear life” over other conventional methods.

Painting - Thermoplastic polyester resin can be successfully painted by conventional techniques using commercially available coating systems. Although high bake temperature coatings can be employed without severe distortion or part warpage, an additional 0.1 - 0.2% part shrinkage can occur.

Coating systems for thermoplastic polyester resins generally consist of a primer coat and a top coat. In the automotive industry, coating systems for thermoplastic polyester resins are specified by the end-user. Therefore, if a thermoplastic polyester resin is used in an application where painting is specified, contact the end-user or a Ticona representative for detailed information.

Hot Stamping - Thermoplastic polyester resins have been successfully hot stamped using standard equipment and commercially available hot stamping foils. A wide selection of foils is available through foil manufacturers to cover pigmented and metallized coatings in glossy, semi-gloss, and flat finishes.

In selecting the coating type, consideration must be given to such qualities as abrasion, oil, grease, chemical or product resistance which must be incorporated into the foil.

Because of the need to match the hot stamping foil with the particular application, it is not feasible to list standard foils for polyesters in this publication. Each application should be discussed with the foil manufacturer to insure that the final product successfully meets the end-use requirements.

In-Mold Decorating - Labels, films, and foils may be in-mold decorated on molded parts. To make the process feasible, part geometry must be simple, and molding cycles may be slightly longer. Automatically indexed decorations require special handling equipment and may require special mold design.

Printing

Various printing methods can be used to apply graphics, serial numbers, bar/lot codes, etc. to finished thermoplastic polyester parts. These methods include offset printing, silk screening, pad printing, sublimation printing, and laser marking.

Sublimation Printing - Sublimation (or diffusion) printing is a textile process in which color patterns in dry dye crystals are transferred from a release film to the fabric under high heat and pressure. This process has been adapted to plastics and is generally limited to polyester and polyester-based alloys due to the availability of dye technology from the textile industry. However, new dyes are under development and the process is being applied to more plastics.

The equipment is very similar to that used for hot stamping. Under heat and pressure, the dye crystals sublime (go directly to the vapor phase from the solid phase without melting) and the vapor penetrates the plastic part. As a result, the decoration is very durable and resistant to wear. It is also cost competitive against other processes such as two-stage injection molding or silk screening.

Laser Marking - Lasers can be used to permanently mark polyester parts to a depth of 0.002 inches without using inks, dyes or paints. Laser markings can be placed on parts with matte finishes and curved surfaces as well as smooth finishes and flat surfaces.

Laser marking provides more contrast than “molded-in” raised or indented markings. White marks can be placed on black or dark surfaces and dark markings can be placed on white or light colored parts.

Although most laser marking of polyester is accomplished with the Nd:Yag laser, the Excimer laser has also been used to successfully mark white polyester with a dark mark.

Black Celanex 3300LM (30% glass-filled), 4300LM (30% glass-filled, improved impact), and 6500LM (30% glass/mineral filled) polyesters have been enhanced for use in applications requiring laser marking. Black polyester parts, in addition to those made of white, gray, tan, blue and yellow polyester, have all been successfully marked using the Nd:Yag laser. For more information on laser marking, call Product Information Services at 1-800-833-4882.

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