DuPont™ Vespel® TP-8000 Series Design Handbook

SUITABLE FOR MECHANICAL COMPONENTS REQUIRING THERMAL RESISTANCE, WEAR AND FRICTION PERFORMANCE, AND HIGH ELECTRICAL PERFORMANCE

A number of recent innovations in both product development and fabrication technology have led to a family of thermoplastic polyimide products that offer the design engineer practical, cost-competitive solutions to difficult problems in high temperature applications. Vespel® TP-8000 Series parts are particularly adapted to applications where thermal stability, electrical properties, wear and friction behavior are required in mechanical components.

Today's competitive markets place a premium on the role of the design engineer, both in designing new products and redesigning existing ones. Vespel® parts, like all plastic parts, are governed by the same rules for good design and by the same physical laws as other materials. Therefore, the intent of this manual is to help designers apply these principles to the selection, testing and specification of Vespel® TP-8000 Series parts.

This design manual contains comprehensive physical property and performance data on the TP-8000 Series resins from which corresponding Vespel® parts are made. All of the data in the sections that follow are the result of physical property testing conducted by DuPont or its partners. The selection of data for this manual has been made in consultation with design engineers responsible for DuPont™ Vespel® 8000 Series applications. End-use testing is always recommended.

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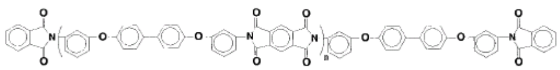
INTRODUCTION

Chemistry

DuPont™ Vespel® TP-8000 Series is a group of products based on semi-crystalline polyimide having a T_g of 250°C and a T_m of 388°C. However, the molded products are amorphous because the crystallization speed is slower than that of typical semi-crystalline polymers. TP-8000 can be used up to 240°C in the as-molded amorphous state, whereas it can be used above 240°C up to 320°C when crystallized after molding. However, since maximum use temperature is dependent on a number of factors, contact your local Vespel® Technical resource for guidance.



Product Overview

The TP-8000 series includes several different products that cover a wide array of high temperature and high wear applications. The table below gives a brief overview of the product offering. While this design manual covers these standard TP-8000 grades, several specialty grades are available. Please contact your local Vespel® Technical resource to discuss your specific application in more detail so that a suitable TP-8000 Series product can be identified.

Fabrication Methods

Since TP-8000 series products are thermoplastic, they can be fabricated into articles using melt processing techniques such as injection molding, extrusion, and thermoforming. This geometric flexibility gives design engineers unprecedented freedom to creatively solve most design problems without the added cost of a secondary machining operation. Furthermore, given the geometric flexibility that comes with these products, multiple components may be incorporated into a single part, reducing tooling, inventory and part handling costs. When metal or ceramic mating components are required, insert-molding Vespel® TP is always an option-adding more design flexibility and overall part functionality.

Defining the End-Use Requirements

The most important first step in designing a plastic part is to define properly and completely the environment in which the part will operate. Properties of plastic materials are substantially altered by temperature, chemical exposure, and applied stress. These environmental effects must be defined on the basis of both short and long term exposure conditions. Time under stress and environment is important in determining the extent to which properties, and thus the performance of the part will be affected. If a part is to be subject to temperature changes in the end-use, it is not enough to define the maximum temperature to which the part will be exposed. The total time the part will be at that temperature during the design life of the device must also be calculated. The same applies to stress resulting from an applied load. If the stress is applied intermittently, the time it is applied and the frequency of occurrence is very important. Plastic materials are subject to creep under applied stress and the creep rate is accelerated with increasing temperature. If loading is intermittent, the plastic part will recover to some extent, depending upon the stress level, the duration of time the stress is applied, the length of time the stress is removed or

Vespel® TP Grade	Nominal Composition	Performance Overview	Typical Applications
TP-8054	Unfilled	General purpose unfilled grade used in insulating applications	Electrical bushings, thermal and electrical Insulator rings and pads, connectors, switches
TP-8395	PTFE, Graphite Blend	Used for wear applications where the countersurface is highly polished or a soft metal	Wear rings, washers, seal rings
TP-8212	30% Glass Filled	High modulus grade used in insulating applications that do not require wear resistance (Glass is aggressive towards countersurface).	Brackets, thermal and electrical insulators
TP-8130	30% Carbon Fiber Filled	Internally lubricated, high modulus grade used in both dry and lubricated wear environments.	Thrust washers, bushings bearings, wear pads and strips
TP-8311	10% Carbon Fiber Filled	Medium modulus grade used in both dry and lubricated wear environments	Fairings, wear strips and pads,
TP-8549	30% Carbon Fiber Filled	High modulus grade similar to TP-8130 but offers improved wear performance and chemical resistance.	Thrust washers, bushings bearings, wear pads and strips
TP-8792	15% Carbon Fiber, 15% PTFE Filled	Similar in strength to TP-8311 with better wear resistance at high speeds in lubricated environments	Seal rings, piston rings, vanes

reduced, and the temperature during each time period. The effect of chemicals, lubricants, etc., is likewise time and stress dependent. Some materials may not be affected in the unstressed state, but will stress crack when stressed and exposed to the same reagent over a period of time. A design checklist is included in Appendix A to serve as a guide when defining the end-use requirements.

Prototyping the Design

In order to move a part from the design stage to commercial reality, it is often necessary to produce prototype parts for testing and modification. The preferred method for making prototypes is to simulate as closely as practical the same process by which the parts will be made in commercial production. Most engineering plastic parts are made in commercial production via the injection molding process, thus, the prototypes should be made using a single cavity prototype mold or a test cavity mounted in the production mold base. The reasons for this are sound, and it is important that they be clearly understood. The discussion that follows will describe the various methods used for making prototypes, together with their advantages and disadvantages.

Machining from Rod or Plaque Stock

This method is commonly used where the design is very tentative and a small number of prototypes are required, and where relatively simple part geometry is involved. Machining of complex shapes, particularly where more than one prototype is required, can be expensive. Machined parts can be used to assist in developing a more firm design, or even for limited testing, but are not recommended for final evaluation prior to commercialization. The reasons are as follows:

- Properties such as strength, toughness and elongation will likely be lower than that of the molded part because of machine tool marks on the sample part.
- If fiber reinforced resin is required, the effects of fiber orientation can be misleading. It is common for machined parts from fiber filled product to have less than half the strength than that in molded form. Furthermore, if machined parts will be used for wear testing, the exposed fiber ends for fiber filled resins might lead to misleading test results versus actual performance from a molded article.
- Surface characteristics such as knockout pin marks, gate marks and mold parting line found in molded parts will not be represented in the machined part.
- The effect of knit lines in molded parts cannot be studied.
- Dimensional stability may be misleading due to gross differences in internal stresses and fiber orientation, if fiber reinforced products are used.
- Voids commonly found in the center of rod and plaque stock can reduce part strength. By the same token, the effect of voids sometimes present in heavy sections of a molded part cannot be evaluated.
- There may be a limited selection of resins available in rod or plaque stock.

Prototype Tool

A better alternative to machined prototypes is to mold the part in a prototype tool. This approach better simulates a production molded part. Basic information will then be available for mold shrinkage, fiber orientation and gate position. This type of tool will provide parts which are more suitable for end-use testing, and it can potentially be modified to accommodate changes in geometry and dimensions.

Preproduction Tool

The best approach for design developments of precision parts is the construction of a preproduction tool. This can be a single cavity mold, or a single cavity in a multi-cavity mold base. The cavity will have been machine finished but not hardened, and therefore some alterations can still be made. It will have the same cooling as the production tool so that any problems related to warpage and shrinkage can be studied. With the proper knockout pins, the mold can be cycled as though on a production line so that cycle times can be established. And most importantly, these parts can be evaluated for dimensions and geometry, strength, impact, wear, and other physical properties in the actual or simulated end-use environment.

Testing the Design

Every design should be thoroughly tested while still in the prototype stage. Early detection of design flaws or faulty assumptions will save time, labor, and material. The following are general options for validating the final design:

- *Actual end-use testing* is the best test of the prototype part. All performance requirements are encountered here, and a complete evaluation of the design can be made.
- *Simulated service tests* can be conducted. The value of such tests depends on how closely end-use conditions are duplicated. For example, an under hood automotive part might be given temperature, vibration and hydrocarbon resistance tests; a bracket might be subjected to abrasion and impact tests; and an electronic component might undergo tests for electrical and thermal insulation.
- *Field testing* is highly recommended. However, long-term field or end-use testing to evaluate the important effects of time under load and temperature is sometimes impractical or uneconomical. Accelerated test programs permit long-term

performance predictions based upon short term "severe" tests; but discretion is necessary. The relationship between long vs. short term accelerated testing is not always known. Your DuPont representative should be consulted when accelerated testing is contemplated.

Writing Meaningful Specifications

A specification is intended to satisfy functional, aesthetic and economic requirements by controlling variations in the final product. The part must meet the complete set of requirements as prescribed in the specifications. The designers' specifications should include:

- Specific TP-8000 Series grade
- Surface finish
- Parting line location desired
- Flash limitations
- Permissible gating and knit line areas (away from critical stress points)
- Permissible knockout pin locations
- Locations where voids are intolerable
- Allowable warpage
- Tolerances

PERFORMANCE PROPERTIES

DuPont™ Vespel® TP-8000 Series products are near the top of the engineering polymers performance pyramid. The following sections will illustrate the capability of these products across a broad temperature range and demonstrate their potential use in a wide variety of demanding applications. Typical properties are summarized in **Tables 1** and **2**.

Mechanical Properties

Vespel® TP-8000 series products offer excellent mechanical performance in demanding environments, particularly at high temperature. These products are candidates for fabrication of components used in elevated temperature environments.

Figures 1–3 show mechanical performance across a broad temperature range. TP-8000 retains significant strength even at temperatures as high as 150°C, beyond the capabilities of many other thermoplastic materials. Whether your application is subjected to tensile, flexural, or compressive stresses at elevated temperatures, TP-8000 is a logical candidate for initial evaluations.

Since most designers are interested in the stress-strain behavior, stress-strain curves for each grade in tension and compression are provided in Appendix B.

Figure 1. Tensile Strength as a Function of Temperature (ISO 527)

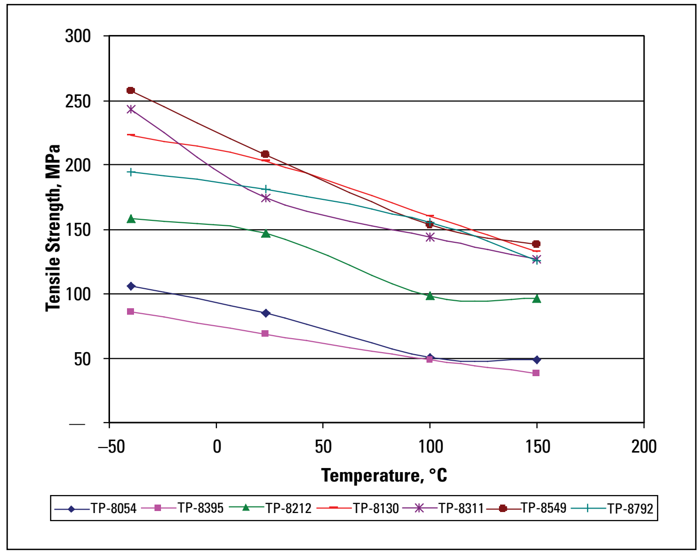


Figure 2. Flexural Strength as a Function of Temperature (ISO 178)

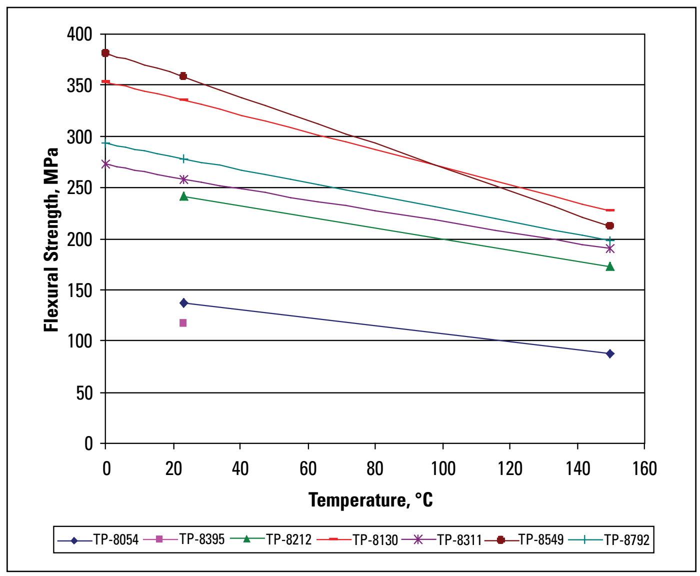


Figure 3. Compression Strength as a Function of Temperature (ISO 604)

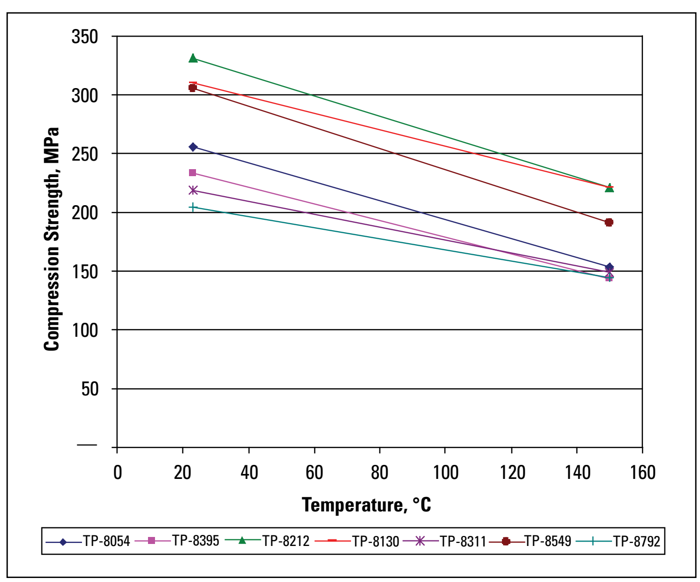


Table 1
Typical Properties (English Units)

Properties	Test Method	Units	TP-8054	TP-8395	TP-8212	TP-8130	TP-8311	TP-8549	TP-8792
Mechanical									
Tensile Strength, –40°F 73°F 212°F 302°F	ISO 527	kpsi	15.4 12.3 7.3 7.0	12.5 9.9 7.0 5.5	23.0 21.3 14.2 14.0	32.4 29.5 23.2 19.2	35.2 25.3 20.9 18.4	37.3 30.2 22.3 20.1	28.2 26.2 22.5 18.3
Tensile Elongation, –40°F 73°F 212°F 302°F	ISO 527	%	13 92 102 94	9 14 7 8	2 2 1 1	1 1 1 1	1 2 2 2	1 1 1 1	2 2 2 1
Tensile Modulus, –40°F 73°F 212°F 302°F	ISO 527	kpsi	220 163 108 90	213 175 151 117	1,490 1,490 943 865	3,780 3,260 3,170 3,050	4,100 1,620 1,560 1,930	3,920 3,530 3,300 2,770	2,100 2,410 2,230 2,160
Flexural Strength, 32°F 73°F 302°F	ISO 178	kpsi	— 19.9 12.8	— 17.0 —	— 35.0 25.0	51.3 48.7 32.9	39.6 37.5 27.7	55.2 51.9 30.8	42.6 40.3 28.7
Flexural Modulus, 32°F 73°F 302°F	ISO 178	kpsi	— 427 370	377 — —	— 1,400 1,200	3,000 3,054 2,854	1,430 1,502 1,391	3,148 3,142 2,774	1,960 2,047 1,926
Compressive Strength, 32°F 73°F 302°F	ISO 604	kpsi	— 37.1 22.3	— 33.8 20.9	— 48.0 32.0	44.8 45.0 32.0	33.2 31.8 21.6	44.2 44.4 27.7	29.4 29.7 21.0
Compressive Modulus, 32°F 73°F 302°F	ISO 604	kpsi	— 197 166	— 197 182	— 391 365	410 445 434	348 413 365	426 417 388	403 387 389
Izod Impact Strength notched	ASTM D256	ft-lbs/in	1.7	1.5	2.2	2.4	2.4	2.4	2.4
Poisson's Ratio			0.34	0.29	0.30	0.45	0.43	0.48	0.46
Thermal									
Deflection Temperature Under Load, 264 psi	ASTM D648	°F	460	446	475	475	475	462	475
Coefficient of Linear Thermal Expansion Flow Direction Cross-Flow Direction	ASTM E228	10^{-5} in/in/°F	2.7 2.9	2.7 2.9	0.9 2.9	0.3 2.6	0.9 2.8	0.6 2.0	0.3 2.9
Thermal Conductivity	ASTM C177	W/m K	0.17	—	0.34	—	—	—	—
Specific Heat 73°F 212°F 572°F	DSC	BTU/lb°F	0.24 0.24 0.34	— — —	0.23 0.23 0.32	— — —	— — —	— — —	— — —
Electrical									
Dielectric Constant 1 kHz 1 MHz	IEC 60250		2.9 2.9	3.1 3.0	3.4 3.3	100.6 43.2	6.7 6.0	70.2 34.3	28.1 13.1
Dissipation Factor 1 kHz 1 MHz	IEC 60250		0.001 0.006	0.001 0.006	0.002 0.006	3.796 0.212	0.039 0.019	0.524 0.162	0.260 0.116
Dielectric Strength	IEC 60243	kV/mm	30.9	28.3	30.3	—	—	—	—
Surface Resistivity	IEC 60093	Ohm/Sq	5.0E+17	3.3E+16	1.4E+17	1.8E+06	2.7E+14	8.4E+06	3.9E+11
Volume Resistivity	IEC 60093	Ohm-cm	5.0E+17	8.7E+17	9.1E+16	1.4E+06	1.3E+15	1.2E+07	2.1E+10
General									
Specific Gravity	ASTM D 792		1.33	1.38	1.56	1.43	1.35	1.42	1.46
Water Absorption, 24 hr at 73°F	ASTM D 570	%	0.34	0.20	0.23	0.23	0.23	0.08	0.20

Table 2
Typical Properties (SI Units)

Properties	Test Method	Units	TP-8054	TP-8395	TP-8212	TP-8130	TP-8311	TP-8549	TP-8792
Mechanical									
Tensile Strength, –40°C 23°C 100°C 150°C	ISO 527	MPa	106 85 50 48	86 68 48 38	158 147 98 96	223 203 160 132	243 174 144 127	257 208 154 138	194 181 155 126
Tensile Elongation, –40°C 23°C 100°C 150°C	ISO 527	%	13 92 102 94	9 14 7 8	2 2 1 1	1 1 1 1	1 2 2 2	1 1 1 1	2 2 2 1
Tensile Modulus, –40°C 23°C 100°C 150°C	ISO 527	MPa	1,520 1,120 742 621	1,470 1,210 1,040 804	10,200 10,200 6,500 6,000	26,100 22,500 21,900 21,000	28,300 11,200 10,700 13,300	27,000 24,300 22,800 19,100	14,400 16,600 15,400 14,900
Flexural Strength, 0°C 23°C 150°C	ISO 178	MPa	— 137 88	— 117 —	— 241 172	353 336 227	273 258 191	380 358 212	294 278 198
Flexural Modulus, 0°C 23°C 150°C	ISO 178	MPa	— 2,942 2,549	— 2,598 —	— 9,646 8,268	20,670 21,042 19,664	9,853 10,349 9,584	21,690 21,648 19,113	13,504 14,104 13,270
Compressive Strength, 0°C 23°C 150°C	ISO 604	MPa	 — 256 154	 — 233 144	 — 331 220	 309 310 220	 229 219 149	 305 306 191	 203 205 145
Compressive Modulus, 0°C 23°C 150°C	ISO 604	MPa	 — 197 166	 — 197 182	 — 391 365	 410 445 434	 348 413 365	 426 417 388	 403 387 389
Izod Impact Strength notched	ASTM D256	J/m	90.8	80.1	117.5	128.2	128.2	128.2	128.2
Poisson's Ratio			0.34	0.29	0.30	0.45	0.43	0.48	0.46
Thermal									
Deflection Temperature Under Load, 1.8 MPa	ASTM D648	°C	238	230	246	246	246	239	246
Coefficient of Linear Thermal Expansion Flow Direction Cross-Flow Direction	ASTM E228	10^{-5} cm/ cm/°C	 4.9 5.2	 4.9 5.2	 1.6 5.2	 0.5 4.7	 1.6 5.1	 1.1 3.6	 0.5 5.2
Thermal Conductivity	ASTM C177	W/m K	0.17	—	0.34	—	—	—	—
Specific Heat 23°C 100°C 300°C	DSC	BTU/lb f	 0.24 0.24 0.24	 — — —	 0.23 0.23 0.32	 — — —	 — — —	 — — —	 — — —
Electrical									
Dielectric Constant 1 kHz 1 MHz	IEC 60250		 2.9 2.9	 3.1 3.0	 3.4 3.3	 100.6 43.2	 6.7 6.0	 70.2 34.3	 28.1 13.1
Dissipation Factor 1 kHz 1 MHz	IEC 60250		 0.001 0.006	 0.001 0.006	 0.002 0.006	 3.796 0.212	 0.039 0.019	 0.524 0.162	 0.260 0.116
Dielectric Strength	IEC 60243	kV/mm	30.9	28.3	30.3	—	—	—	—
Surface Resistivity	IEC 60093	Ohm/sq	5.0E+17	3.3E+16	1.4E+17	1.8E+06	2.7E+14	8.4E+06	3.9E+11
Volume Resistivity	IEC 60093	Ohm-cm	5.0E+17	8.7E+17	9.1E+16	1.4E+06	1.3E+15	1.2E+07	2.1E+10
General									
Specific Gravity	ASTM D 792		1.33	1.38	1.56	1.43	1.35	1.42	1.46
Water Absorption, 24 hr at 23°C	ASTM D 570	%	0.34	0.20	0.23	0.23	0.23	0.08	0.20

Thermal Properties

Dynamic Mechanical Analysis (DMA)

While most designers are comfortable with HDT as an indicator of how a material will perform at elevated temperatures, DMA offers more insight into how a material might respond in a given environment.

DMA provides valuable data for characterizing the thermal performance of polymers. DMA measures the amplitude and phase of a sample's displacement in response to an applied oscillating force. The stiffness of the sample is calculated from this data and converted to a modulus to enable inter-sample comparison. Tan δ, the loss tangent or damping factor, is also calculated. A temperature scan at constant frequency can generate a fingerprint of the material's relaxational processes and its glass transition temperature (T_g). This technique provides the most sensitive method for measuring T_g.

Figures 4 and **5** show the DMA results for TP-8054 and TP-8130 respectively. These curves are helpful to designers seeking to identify the T_g and understand the stiffness of a component at a certain temperature. The designer may also better understand the dimensional stability of precision parts at temperature since thermal expansion coefficients can increase dramatically above the T_g.

Thermal Aging

TP-8000 Series resins offer long-term thermal stability at elevated temperatures. To help illustrate this performance, test specimens were aged at 200°C for 5000 hours while monitoring their tensile strength and elongation retention. **Figure 6** shows complete retention of tensile strength even after 5000 hr at 200°C. **Figure 7** shows a significant retention of elongation after the same period.

Figure 4. DMA Curve for TP-8054

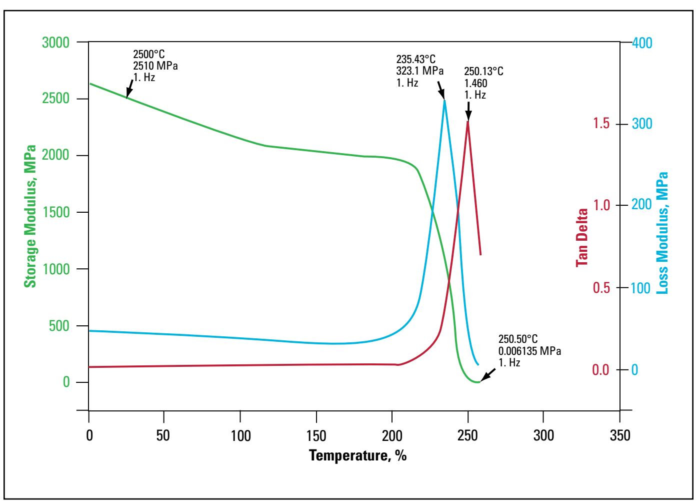


Figure 5. DMA Curve for TP-8130

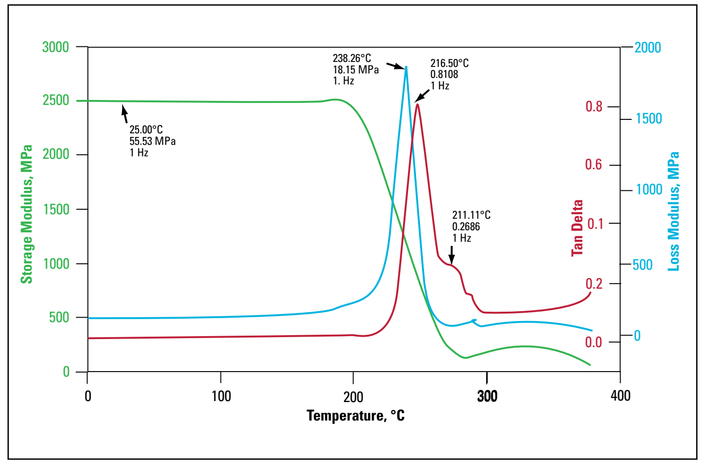


Figure 6. Tensile Strength Retention of TP-8054 after Aging at 200°C (ISO 527)

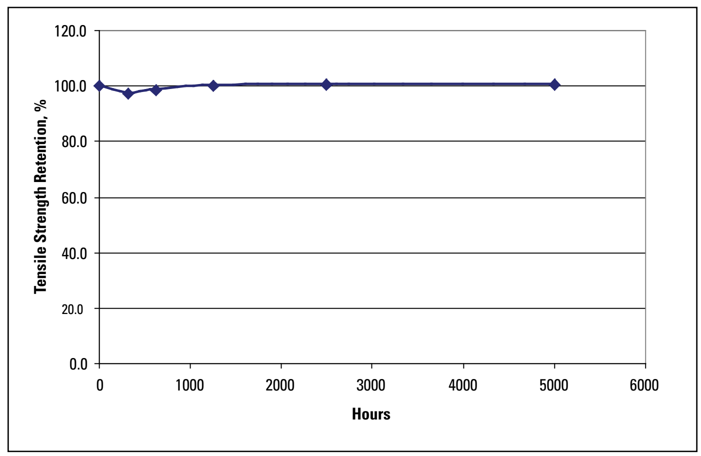
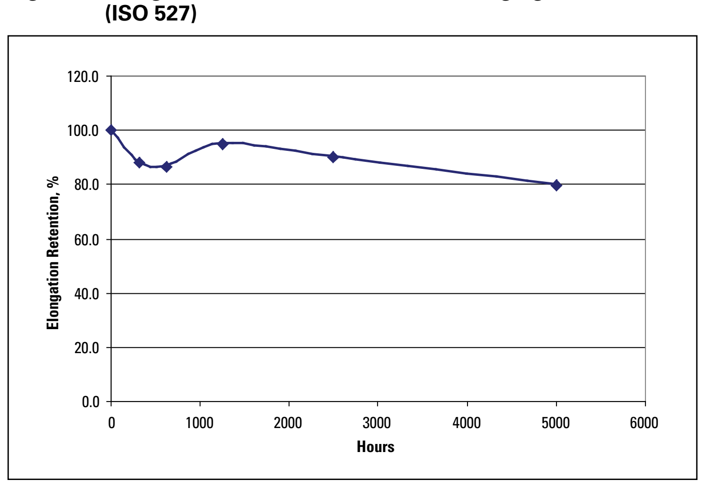


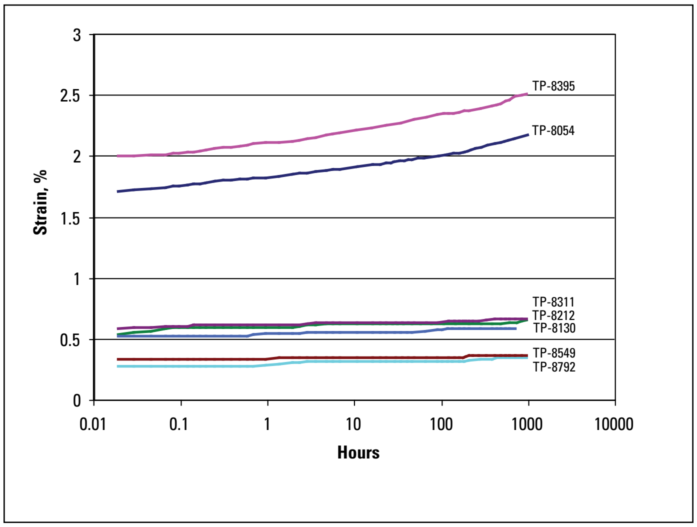
Figure 7. Elongation Retention of TP-8054 after Aging at 200°C (ISO 527)



Flexural Creep

Plastics tend to deform over time when exposed to a sustained load. This is known as creep. The designer should account for creep in applications that will expose the component to a long-term load. Like other performance attributes, creep will be influenced by the magnitude of the applied load as well as the temperature at which the load is applied. The flexural creep performance for TP-8000 products at 23°C and 48 MPa (7,000 psi) is shown in **Figure 8**. Typically, unfilled or lightly filled products will exhibit higher creep, as seen here. Appendix C contains flexural creep data for each grade at elevated temperature.

Figure 8. Flexural Creep at 23°C/48 MPa (7,000 psi) (ASTM D 2990)



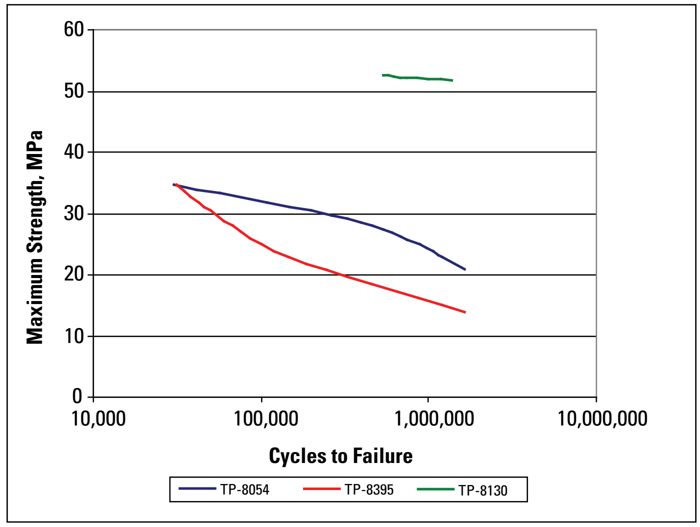
Flexural Fatigue

Some applications stress components by cyclical loading or vibration. Flexural, compressive, shear (twist) or tensile loading may result. Repeated cyclic loading causes a deterioration of mechanical performance and potentially leads to complete failure. Fatigue resistance data is important to designers for any part that will be used in an application that involves cyclic loading such as gears, rollers or components in vibrating equipment. **Figure 9** shows the flexural fatigue performance of select TP-8000 grades.

Tribological Properties

One of the main performance attributes of DuPont™ Vespel® TP-8000 Series products is their wear and friction behavior. Wear and friction performance is not a material attribute, but the resulting performance of the interaction of two materials.

Figure 9. Flexural Fatigue, at 75 kHz (ASTM D 671)



Factors such as load, velocity, dry or lubricated environment, countersurface composition and surface finish and temperature all contribute to wear and friction performance.

To give an indication of wear performance, certain TP-8000 grades were tested under thrust wear conditions. Results are shown in **Tables 3** and **4**. The test is based upon the Suzuki thrust wear method (JIS-K7218A). The washers did not contain grooves. Dry wear testing was conducted over a 7 hr period while lubricated testing was conducted over a 4 hr period. The countersurface was SUS 304 stainless steel. This countersurface material corresponds to ANSI 304 and ISO 683/13 11.

Generally, the highly loaded carbon fiber grades tend to perform well under high load, low speed while grades containing PTFE or PTFE and carbon fiber combination tend to perform well under high speed, low load. Since grade selection will depend on many factors, please consult with a Vespel® Technical Service Representative for assistance in selecting the appropriate grade for your application.

Figure 10. Suzuki Thrust Wear Test Schematic (JIS-K7218A)

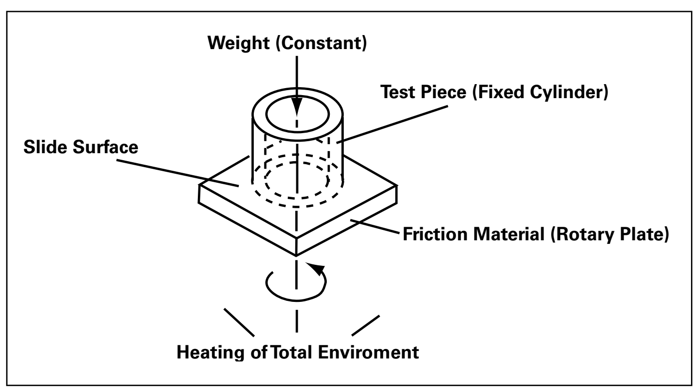


Table 3
Suzuki Thrust Wear Test Results — Dry

Grade	PV psi·ft/min	PV MPa·m/s	friction, μ	wear factor, K 10-10 cm^3/kgfm	resin wear, mg	metal wear, mg
TP-8130	71,000	2.5	0.05	66	10	<1
TP-8130	95,000	3.3	0.04	77	16	<1
TP-8549	71,000	2.5	0.05	49	9	<1
TP-8549	95,000	3.3	0.05	63	14	<1
TP-8311	14,000	0.5	0.10	670	23	<1
TP-8311	28,000	1.0	0.10	490	34	<1

Table 4
Suzuki Thrust Wear Test Results — Lubricated

Grade	PV psi·ft/min	PV MPa·m/s	friction, μ	wear factor, K	resin wear, mg	metal wear, mg
TP-8130	298,000	10.4	0.03	4	2	<1
TP-8130	357,000	12.5	0.03	3	1	<1
TP-8549	298,000	10.4	0.02	3	1	<1
TP-8549	357,000	12.5	0.02	4	2	<1
TP-8311	298,000	10.4	0.02	3	1	<1
TP-8311	357,000	12.5	0.02	2	1	<1
TP-8549	298,000	10.4	0.03	3	2	<1

Electrical Properties

The unfilled and glass filled TP-8000 grades are excellent electrical insulators. The dielectric constant, dissipation factor and dielectric strength for each grade are listed in **Table 5**. The carbon fiber filled grades are not electrical insulating by nature. Therefore, no dielectric strength values are reported. **Table 6** lists the surface and volume resistivity for each grade.

Table 5
Dielectric Constant/Dissipation Factor and Dielectric Strength (23°C, 2.0 mm Thickness)

	Dielectric Contant (IEC 60250)		Dissipation Factor (IEC 60250)		Dielectric Strength (IEC 60243)
	1 kHz	1 MHz	1 kHz	1 MHz	kV/mm
TP-8054	2.9	2.8	0.001	0.006	30.9
TP-8395	3.1	3.0	0.001	0.006	28.3
TP-8212	3.4	3.3	0.002	0.006	30.3
TP-8130	100.6	43.2	3.796	0.212	N/A
TP-8311	6.7	6.0	0.039	0.019	N/A
TP-8549	70.2	34.2	0.524	0.162	N/A
TP-8792	28.1	13.1	0.260	0.116	N/A

Environmental Properties

Chemical Exposure

DuPont™ Vespel® TP-8000 Series is a chemically resistant advanced engineering thermoplastic. It offers resistance against most acids, bases, and organic solvents.

Solvents

Organic solvents in general have little effect on the mechanical and dimensional stability of polyimide parts. Chlorinated and fluorinated solvents such as perchloroethylene and trichloroethylene are recommended for surface cleaning of Vespel® parts. Hydrocarbon solvents such as toluene and kerosene have virtually no effect on polyimide materials. At high temperatures, some solvents containing functional groups such as m-cresol and nitrobenzene can cause swelling of polyimides without substantially reducing its mechanical strength.

Acids

Concentrated mineral acids cause severe embrittlement of polyimide parts in a relatively short time and should be avoided. Generally, dilute acid solutions and aqueous solutions of inorganic salts having acidic pH's have about the same effect on polyimide as water.

Bases

Generally, polyimide resins are susceptible to alkaline attack. Aqueous bases attack polyimides leading to rapid deterioration of properties. All basic solutions with a pH of 10 or greater, including salt solutions, should be avoided. Cleaning agents of a caustic nature are not recommended.

Certain grades of TP-8000 can be annealed to induce crystallization and reduce sensitivity to chemicals such as nitric acid and dichloromethane. **Tables 7** and **8** show the chemical resistance of TP-8054 test specimens when immersed in a wide variety of chemical substances.

Additional chemical resistance data for test specimens and films of TP-8054 can be found in Appendix D.

Table 6
Surface and Volume Resistivity

	Surface Resistivity (IEC 60093) Ohm/sq	Volume Resistivity (IEC 60093) Ohm-cm
TP-8054	5.0E+17	5.0E+17
TP-8395	3.3E+16	8.7E+17
TP-8212	1.4E+17	9.1E+16
TP-8130	1.8E+06	1.4E+06
TP-8311	2.7E+14	1.3E+15
TP-8549	8.4E+06	1.2E+07
TP-8792	3.9E+11	2.1E+10

Table 7
TP-8054 Chemical Resistance — 10 Day Immersion at 23°C

		Appearance After Exposure Amorphous	Crystalline
Hydrochloric Acid	10% Solution Concentrate	No change No change	No change No change
Sulfuric Acid	35% Solution Concentrate	No change Swelling	No change No change
Nitric Acid	35% Solution Concentrate	No change Swelling	No change Slight Craze
Soldium Hydroxide	10% Solution 40% Solution	No change No change	No change No change
Potassium Hydroxide	10% Solution 40% Solution	No change Swelling	No change Slight Craze
Engine Oil		No change	No change
Gear Oil		No change	No change
Toluene		No change	No change
Perchloroethylene		No change	No change
Tricholorethylene		No change	No change
Dichloromethane		Slight Craze	No change
Chloroform		Slight Craze	No change
Gasoline		No change	No change
Kerosene		No change	No change

Table 8
TP-8054 Chemical Resistance — 30 Day Immersion

		Appearance After Exposure Amorphous	Crystalline
Methyl ethyl ketone	23°C	No change	No change
Skydrol (#500b-4)	23°C	No change	No change
Skydrol (#500b-4)	80°C	No change	No change

Oil Exposure

DuPont™ Vespel® TP-8000 Series products exhibit resistance against oil at elevated temperatures. The following tables show TP-8054's outstanding retention of properties and appearance when a test specimen is immersed in common oils such as engine, gear, brake, sour gas, synthetic fuel and gasohol.

Results show that the properties and appearance do not change even under extreme conditions of up to 200°C exposure.

Radiation Exposure

When polymers are used as insulation materials for atomic power plants, medical applications, or aerospace applications, radiation resistance may be an important property. When plastics are irradiated, inter-polymer cross-linking and breakage of the polymer chain may take place simultaneously. According to the extent of these phenomena, polymers may be classified into cross-linking and breakage types.

Table 9
Property Retention After Oil Exposure at Elevated Temperature

TP-8054 Test Specimen Exposure

	Property Retention, % Engine Oil at 7 Days 200°C	Gear Oil at 7 Days 200°C
Tensile Strength at Yield	102	102
Tensile Strength at Break	90	95
Elongation at Break	90	110
Flexural Strength	105	110
Flexural Modulus	100	100
Weight Change	+0.02	+0.06
Appearance	No change	No change

Engine Oil: Toyota Castle Motor-oil Clean Royall II (7.5W–30SE)
Gear Oil: Toyota High-point Gear Oil (85W-90)

Table 10
Property Retention of TP-8054 Film After Oil Exposure

TP-8054 Film Exposure

	Property Retention, % at 23°C			
	Brake Oil		Synthetic Fuel Oil	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	110	115	110	115
Tensile Strength at Break	95	110	95	95
Appearance	No change	No change	No change	No change

Brake Oil: Brake Fluid DOT 3 of Nippon Petroleum Company
Synthetic Fuel Oil: Toluene/iso-octane 60/40 volume %

TP-8054 Film Exposure

	Property Retention, % at 23°C			
	Sour Oil		Gasahol	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	110	115	105	110
Tensile Strength at Break	95	110	105	105
Appearance	No change	No change	No change	No change

Sour Oil: Synthetic Fuel Oil/lauroil peroxide 100/5 weight %
Gasahol: Synthetic Fuel Oil/methanol 100/20 volume %

TP-8054 Film Exposure

	Property Retention, % at 180°C		
	Gear Oil		
	500 hr	1000 hr	2000 hr
Tensile Strength at Yield	110	110	120
Tensile Strength at Break	95	90	105
Appearance	No change	No change	No change

Gear Oil: Showa white pilot S-3 (10W-30)

For example, polymers whose molecular structures tend to have high cross-linking ratios such as polyethylene are called cross-linking type polymers because their heat resistance, weatherability, and stress crack resistance are remarkably improved by radiation. However, more often the generation of a double bond, rearrangement of cis-transformation, or breakage of the main molecular chain by oxidation takes place and various properties decline.

DuPont™ Vespel® TP-8000 Series are cross-linking type polymers which have substantially superior radiation resistance than currently available thermoset or pseudo-thermoplastic polyimides or polyketones.

Figures 11–14 illustrate the radiation resistance of Vespel® TP-8054 to b-ray (Electron Beam) radiation, gamma ray (60Co) radiation, and Neutron irradiation from atomic reactor. All data was measured by the Takasaki Radiation Chemistry Research Establishment of Japan's Atomic Research Institute.

Figure 11. Tensile Strength Retention after Electron Beam Exposure

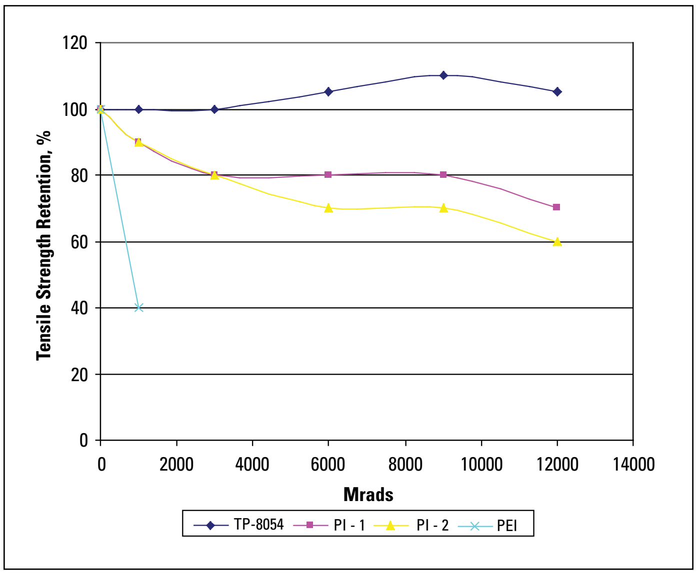


Figure 12. Elongation Retention after Electron Beam Exposure

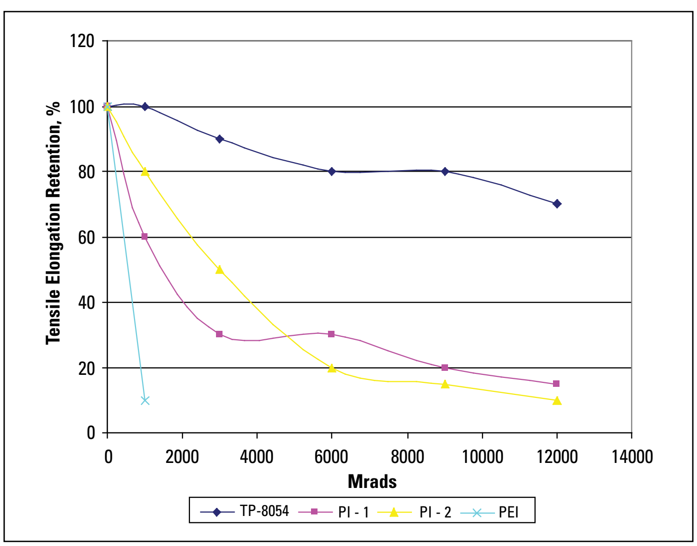


Figure 13. Tensile Elongation Retention after Gamma Irradiation Exposure (Cobalt 60)

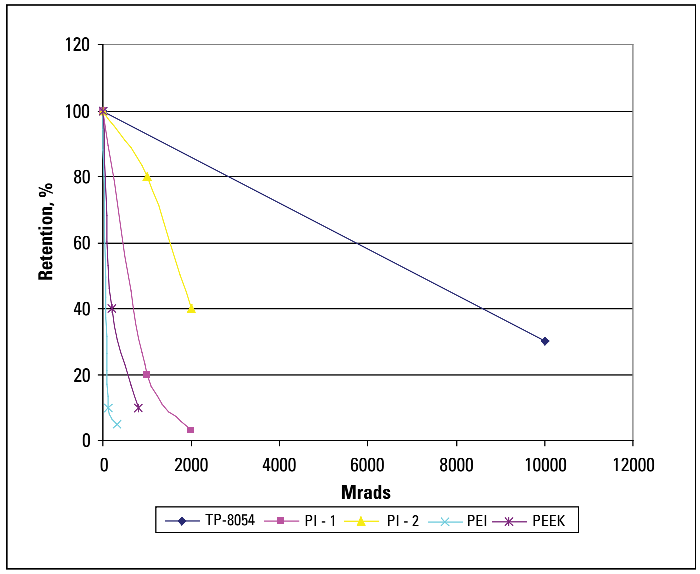
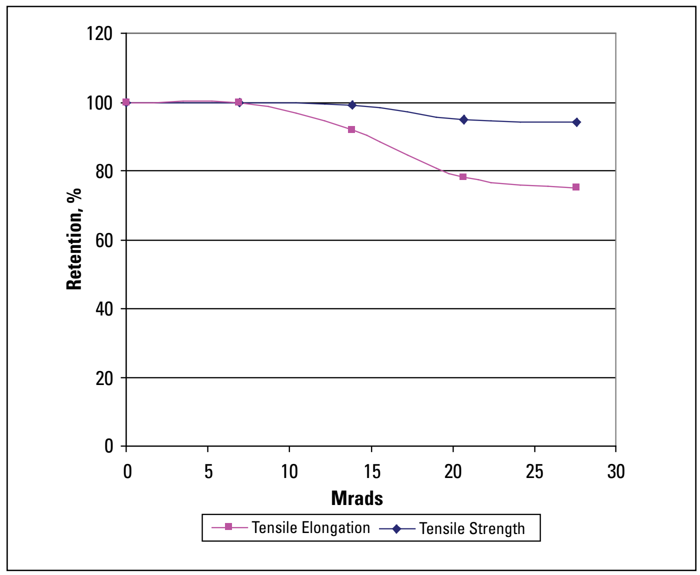


Figure 14. Tensile Property Retention after Neutron Irradiation Exposure



Outgassing Performance

Certain TP-8000 grades offer low outgassing in vacuum environments, making them suitable candidates for clean applications such as semiconductor fabrication and support components. **Figure 15** shows outgassing results per the ASTM E-595 test protocol.

Figure 15. Outgassing Performance Data (ASTM E-595)

Grade	TML, %	CVCM, %	WVR, %
TP-8054	0.587	0.004	0.309
TP-8212	0.410	0.008	0.217

TML : Total Mass Loss CVCM: Collected Volatile Condensable Materials
WVR: Water Vapor Regained

Conditions: Vacuum: 5 x 10^{-5} torr
Heating Element Temperature: 125±1°C
Cooling Element Temperature: 125±1°C
Duration: 24 hr

INJECTION MOLDING

The Process and Equipment

Because most TP-8000 Series components are suitable for fabrication by injection molding, it is important for the designer to understand the molding process, its capabilities and its limitations.

The basic process is very simple. The resin is dried then melted by shear heating and some conduction in the injection molding press. The melt is then injected into a mold under pressure and allowed to cool. Once adequate cooling is achieved, the mold is opened and the parts removed then the mold is closed and the cycle is repeated. **Figure 16** is a schematic of the injection molding machine. **Figure 17** is a schematic cross section of the plastifying cylinder and mold.

The Molding Machine

Melting the plastic and injecting it into the mold are the functions of the plastifying and injection system. The rate of injection and the pressure achieved in the mold are controlled by the machine hydraulic system. Injection pressures range from 35-241 MPa (5,000-35,000 psi). TP-8000 Series melt temperatures vary from a low of about 385°C (725°F) to a high of about 425°C (800°F). Operating at these temperatures can be potentially dangerous if proper safety precautions are not followed. DuPont has taken care to produce parts on appropriately equipped molding machines operated by experienced, dedicated professionals.

The Mold

Mold design is critical to the quality and economics of the injection molded part. Part appearance, strength, toughness, size, shape, and cost are all dependent on the quality of the mold. Key considerations are:

- Proper design for strength to withstand the high pressure involved.
- Correct materials of construction, especially when reinforced resins are used.
- Properly designed flow paths to convey the resin to the correct location in the part without excessive hold-up or temperature variation
- Proper venting of air ahead of the resin entering the mold.
- Carefully designed heat transfer to control the cooling and solidification of the moldings.
- Easy and uniform ejection of the molded parts.

When designing the part, consideration should be given to the effect of gate location and thickness variations upon flow, shrinkage, warpage, cooling, venting, etc. as discussed in subsequent sections. The overall molding cycle can be as short as two seconds or as long as several minutes. The cycle time can be limited by the heat transfer capabilities of the mold, except when machine dry cycle or plastifying capabilities are limiting.

Figure 16. Injection Molding Machine

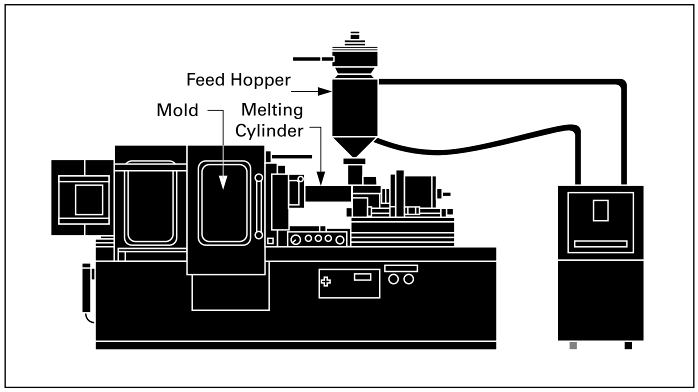
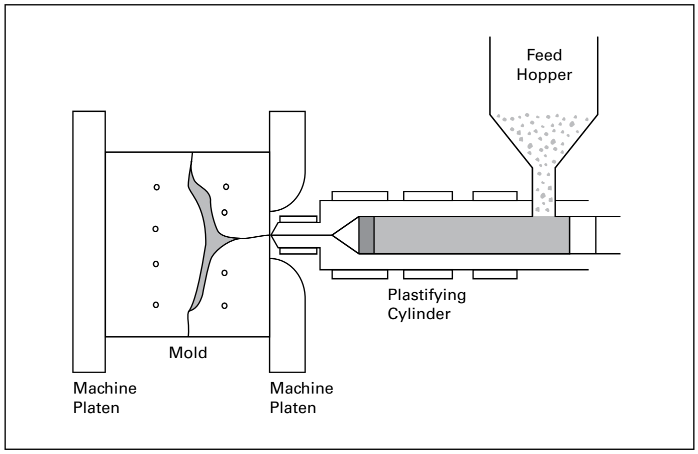


Figure 17. Plastifying Cylinder



MOLDING CONSIDERATIONS

Uniform Walls

Uniform wall thickness in plastic part design is critical. Non-uniform wall thickness can cause warpage and dimensional control problems. If greater strength or stiffness is required, it is more economical to use ribs than increase wall thickness. In parts requiring good surface appearance, ribs should be avoided as sink marks on the opposite surface will surely appear. If ribbing is necessary on such a part, the sink mark is often hidden by some design detail on the surface of the part where the sink mark appears, such as an opposing rib, textured surface, etc. Even when uniform wall thickness is intended, attention to detail must be exercised to avoid inadvertent heavy sections, which can not only cause sink marks, but also voids and non-uniform shrinkage. For example, a simple structural angle (**Figure 18**) with a sharp outside corner and a properly filleted inside corner could present problems due to the increased wall thickness at the corner. To achieve uniform wall thickness use an external radius as shown in **Figure 19**.

Figure 18. Effects on Non-Uniform Wall Thickness on Molded Parts

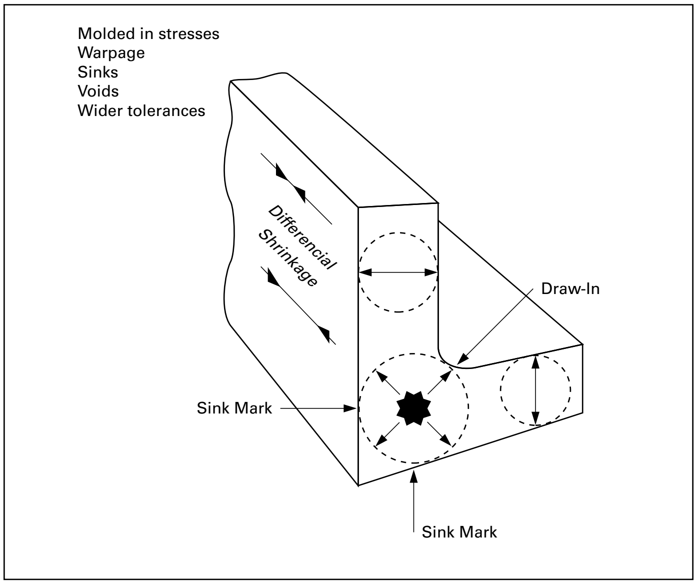


Figure 19. External Radius Illustration, Uniform Wall

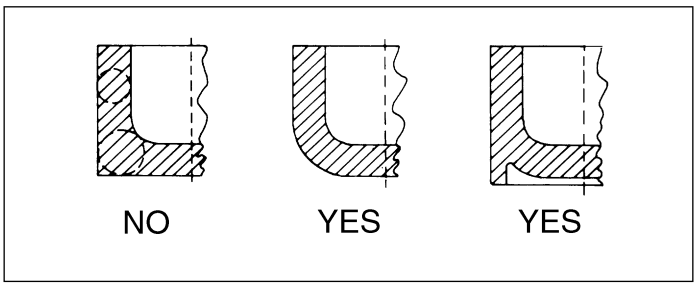


Figure 20. Design Considerations for Maintaining Uniform Walls of Ribs and Bosses

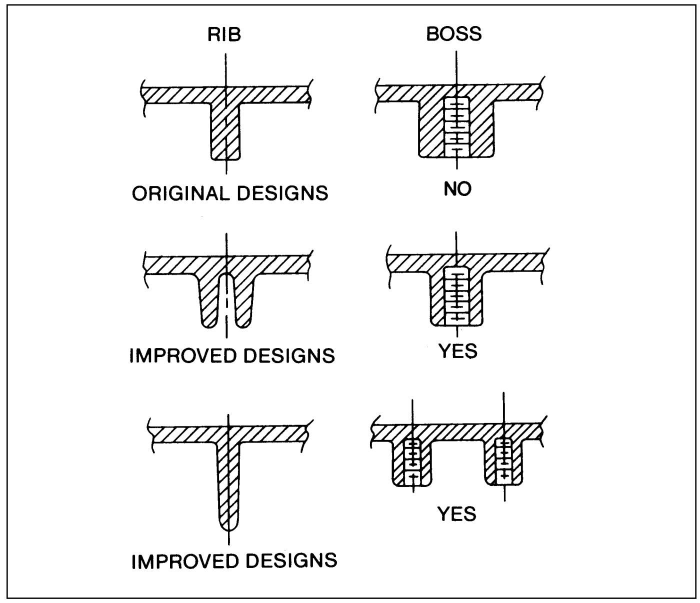


Figure 21. Additional Uniform Wall Considerations

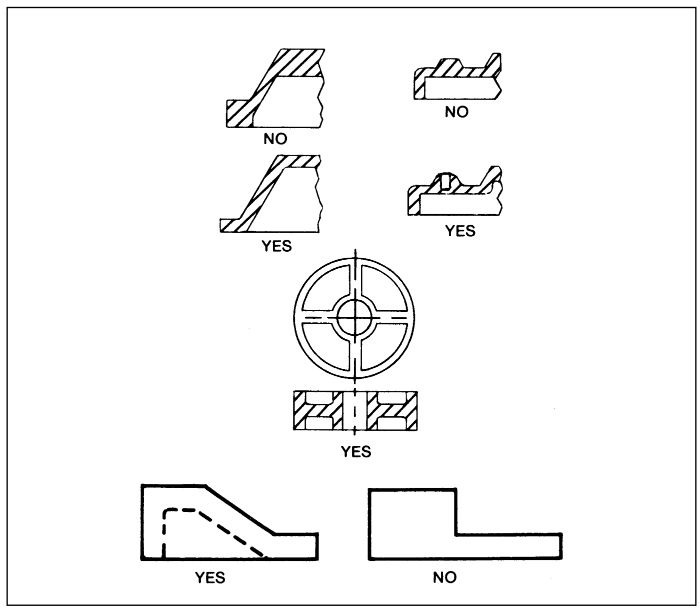
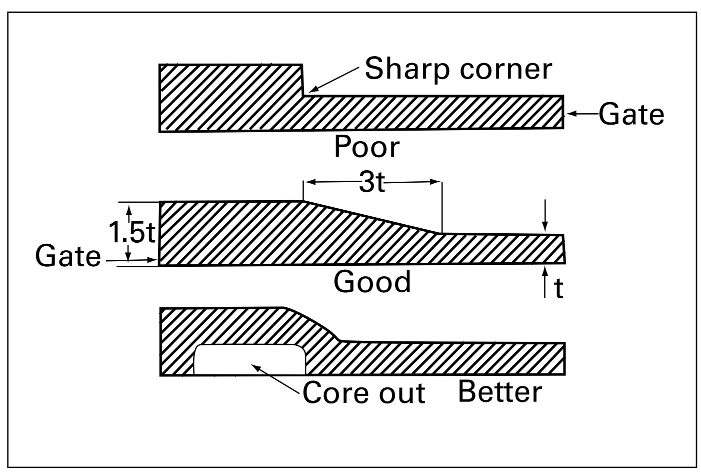


Figure 22. Wall Thickness Transition



Configurations

Other methods for designing uniform wall thickness are shown in **Figures 20** and **21**. Obviously there are many options available to the design engineer to avoid potential problems. Coring is another method used to attain uniform wall thickness. **Figure 21** shows how coring improves the design. Where different wall thicknesses cannot be avoided, the designer should effect a gradual transition from one thickness to another as abrupt changes tend to increase the stress. Further, if possible, the mold should be gated at the heavier section to insure proper packing (see **Figure 22**).

As a general rule, use the minimum wall thickness that will provide satisfactory end-use performance of the part. Thin wall sections solidify (cool) faster than thick sections.

Draft and Ejector Pins

Draft is essential to the ejection of the parts from the mold. Where minimum draft is desired, good draw polishing will aid ejection of the parts from the mold. Use the following table as a general guide.

Table 11
Min. Draft Angle Allowances

	Shallow Draw (less than 1" deep)	Deep Draw (greater than 1" deep)
Unfilled	0–0.25°	0.25–0.50°
Filled	0.25–0.50°	0.50–1.00°

It is important for the designer to be aware of this need inherent to injection molded parts since the draft angle allowance can impact the tolerance capability of certain dimensional features. Your DuPont™ Vespel® Technical Service Representative will assist you in understanding the particular draft needs for a given part.

When knockout pins are used in removing parts from the mold, pin placement is important to prevent part distortion during ejection. Also an adequate pin surface area is needed to prevent puncturing, distorting or marking the parts. In some cases stripper plates or rings are necessary to supplement or replace pins.

Fillets and Radii

Sharp internal corners and notches are perhaps the leading cause of failure of plastic parts. This is due to the abrupt rise in stress at sharp corners and is a function of the specific geometry of the part and the sharpness of the corner or notch. The majority of plastics are notch sensitive and the increased stress at the notch, called the "Notch Effect," results in crack initiation. To assure that a specific part design is within safe stress limits, stress concentration factors can be computed for all corner areas. Formulas for specific shapes can be found in reference books on stress analysis. An example illustrating the stress concentration factor at the corner of a cantilevered beam is shown in **Figure 23**.

It is from this plot that the general rule for fillet size is obtained: i.e., fillet radius should equal one-half the wall thickness of the part. As can be seen in the plot, very little further reduction in stress concentration is obtained by using a larger radius. From a molding standpoint, smooth radii, rather than sharp corners, provide streamlined mold flow paths and result in easier ejection of parts. The radii also give added life to the mold by reducing erosion of the metal. The minimum recommended radius for corners is .5 mm (0.02 in) and is usually permissible even where a sharp edge is required (see **Figure 24**).

Figure 23. Stress Concentration Factors for a Cantilevered Structure

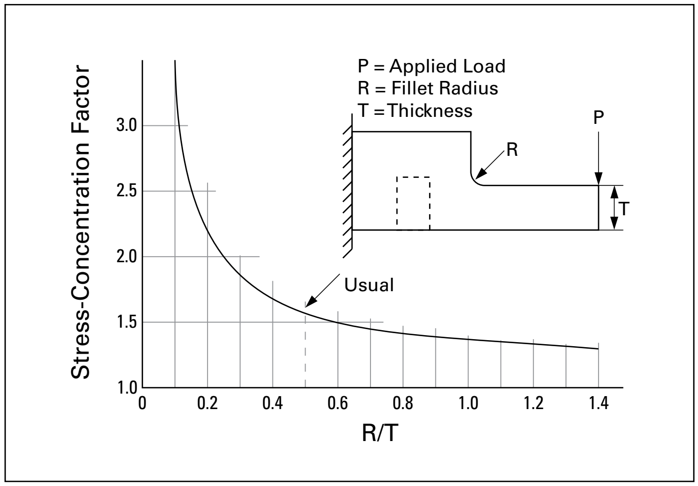
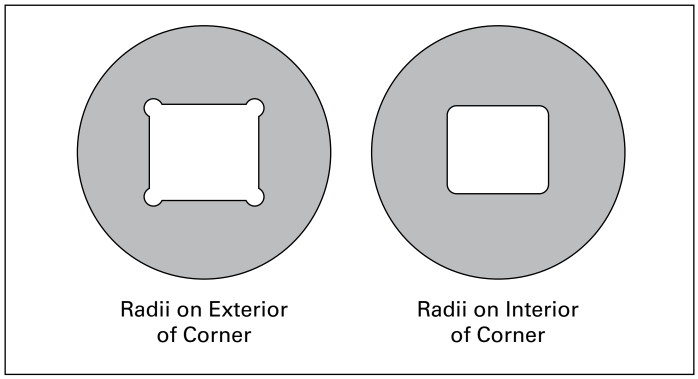


Figure 24. Use of External or Internal Radii



Bosses

Bosses are used for mounting purposes or to serve as reinforcement around holes. Good and poor designs are shown in **Figure 25**. As a rule, the outside diameter of a boss should be 2 to 2.5 times the hole diameter to ensure adequate strength. The same principles used in designing ribs pertain to designing bosses, that is, heavy sections should be avoided to prevent the formation of voids or sink marks, excessive warpage, and cycle time penalty. Boss design recommendations are shown in **Figure 26**.

Ribbing

Reinforcing ribs are an efficient and effective way to improve the rigidity and strength of molded parts. Proper use can save material and weight, shorten molding cycles and eliminate heavy cross section areas which could cause molding problems. Where sink marks opposite ribs are objectionable, they can be hidden by use of a textured surface or some other suitable interruption in the area of the sink. Ribs should be used only when the designer believes the added structure is essential to the structural performance of the part. The word "essential"

Figure 25. Boss Design

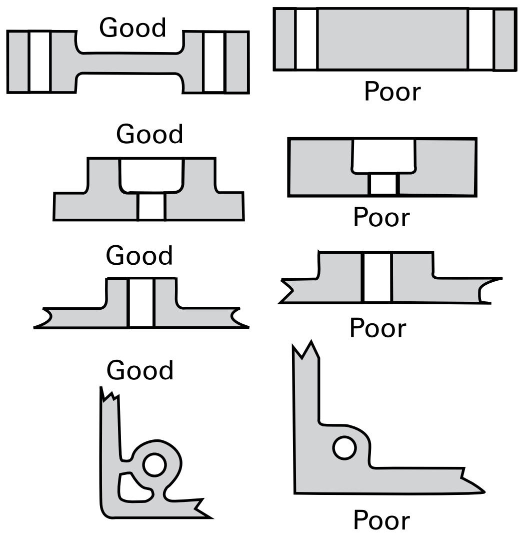
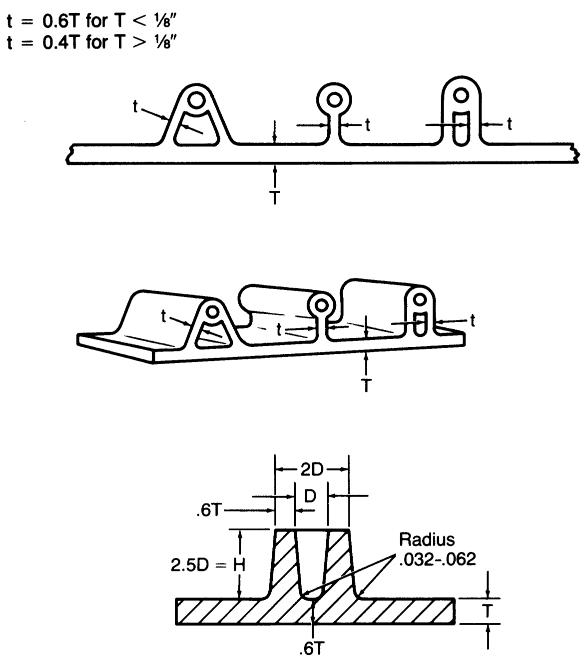


Figure 26. Additional Boss Design Details



must be emphasized, as too often ribs are added as an extra factor of safety, only to find that they produce warpage and stress concentration. It is better to leave any questionable ribs off the drawing. They can easily be added if prototype tests so indicate.

Holes and Coring

Holes are easily produced in molded parts by core pins which protrude into the mold cavity. Through holes are easier to mold than blind holes, because the core pin can be supported at both ends. Blind holes formed by cantilevered pins can be shifted off-center due to deflection of the pin by the flow of molten plastic into the cavity. The depth of a blind hole is generally limited to twice the diameter of the core pin. Design recommendations for cored holes are shown in **Figure 27**. To obtain greater hole depth, a stepped core pin may be used or a side wall may be counterbored to reduce the length of an unsupported core pin (see **Figure 28**).

Holes with an axis which runs perpendicular to the mold-opening direction require retractable core pins or split tools. In some designs this can be avoided by placing holes in walls perpendicular to the parting line, using steps or extreme taper in the wall (see **Figure 29**). Core pins should be polished and draft added to improve ejection. Where knit lines caused by flow of melt around core pins is objectionable from strength or appearance standpoint, holes may be spotted or partially cored to facilitate subsequent drilling as shown in **Figure 30**.

Figure 27. Cored Holes

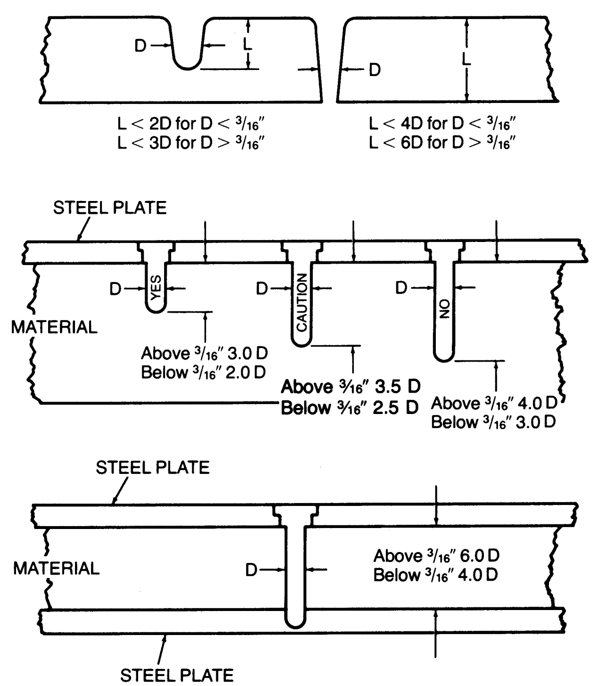


Figure 28. Counterboring Holes

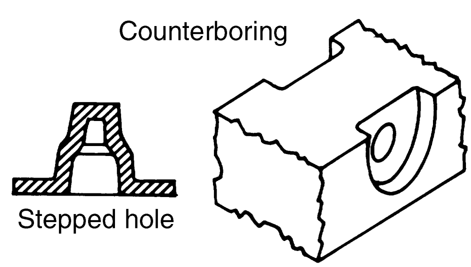


Figure 29. Additional Cored Hole Details

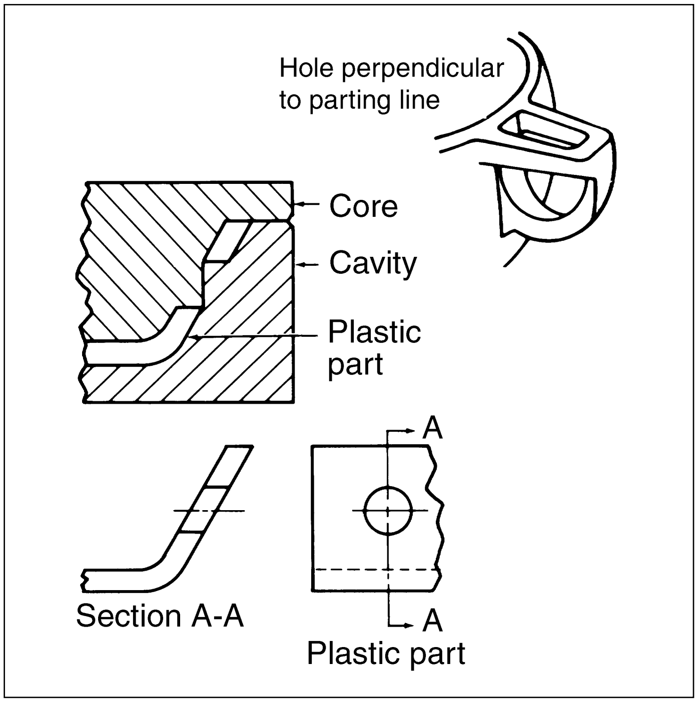
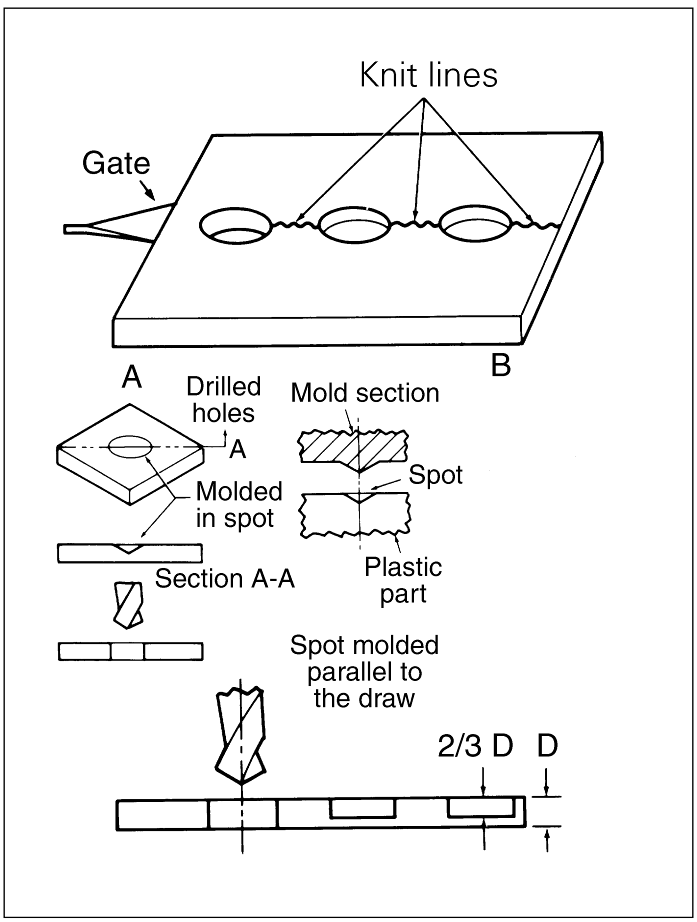
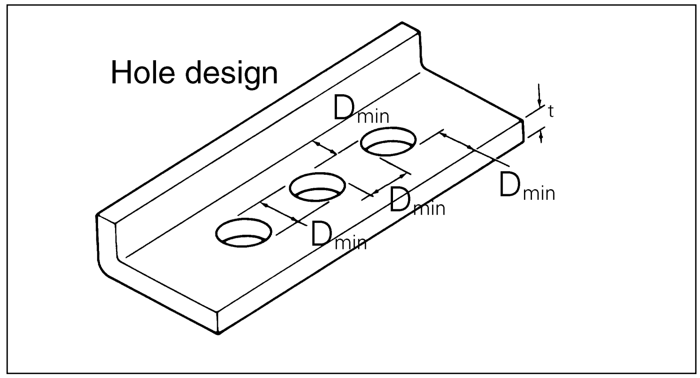


Figure 30. Drilled Holes



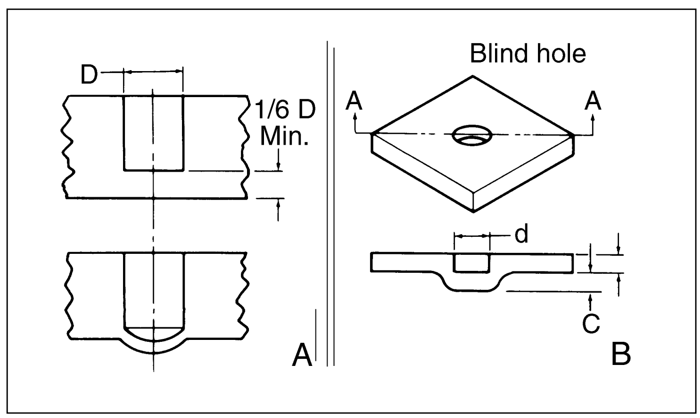
The guide below, referring to **Figure 31**, will aid in eliminating part cracking or tear out of the plastic parts. The minimum distance between holes, from a hole and a bend in the wall, and from the edge of the part should be equivalent to the diameter of the hole.

Figure 31. Hole Design



For a blind hold, thickness of the bottom should be no less than 1⁄6 the hole diameter in order to eliminate bulging (see **Figure 32 A**). **Figure 32 B** shows a better design in which the wall thickness is uniform throughout and there are no sharp corners where stress concentrations could develop.

Figure 32. Blind Holes



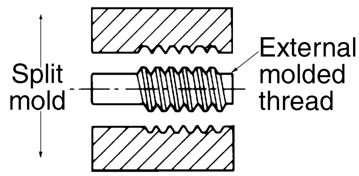
Threads

When required, external and internal threads can be automatically molded into the part, eliminating the need for mechanical thread-forming operations.

External Threads

Parts with external threads can be molded in two ways. The least expensive way is to locate the parting line on the centerline of the thread, **Figure 33**. If this is not acceptable, or the axis of the thread is in the direction of mold-opening, the alternative is to equip the mold with an external, thread-unscrewing device.

Figure 33. Molding External Threads without Side Core



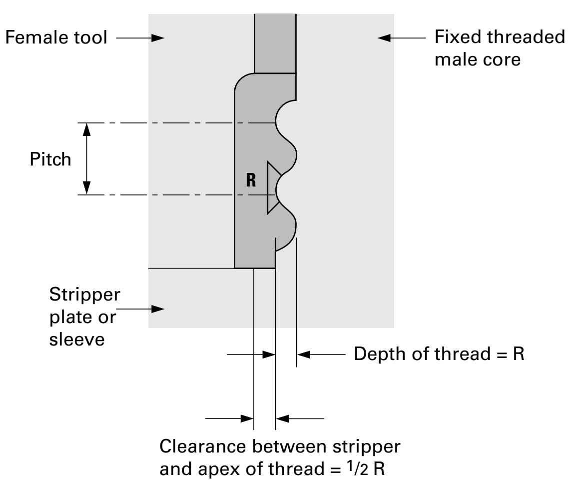
Internal Threads

Internal threads are molded in parts by using automatic unscrewing devices or collapsible cores to produce partial threads. A third method is to use hand-loaded threaded inserts which are removed from the mold with the part.

Stripped Threads

When threaded parts are to be stripped from the mold, the thread must be of the roll or round type. The normal configuration is shown in **Figure 34** where R = 0.288´ pitch. Requirements for thread stripping are similar to those for undercuts. Threaded parts with a ratio of diameter to wall thickness greater than 20 to 1 should be able to be stripped from a mold. **Figures 35** and **36** show the method of ejection from the mold. Stripped threads are recommended for only unfilled grades.

Figure 34. Stripping of Roll-Type Thread



Source: Injection-Mould Design Fundamentals
A. B. Glanville and E. N. Denton
Machinery Publishing Co., London
1965

Figure 35. Mold Ejection of Rounded Thread-Form Undercuts —Male

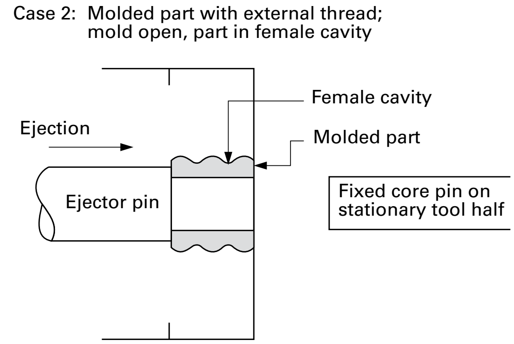
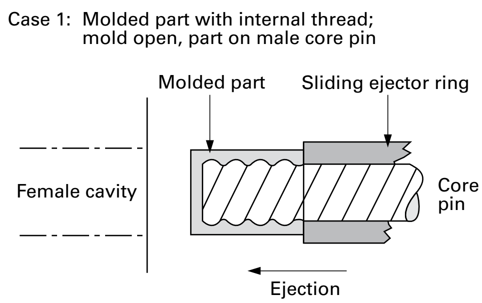


Figure 36. Mold Ejection of Rounded Thread-Form Undercuts —Female



Thread Profile

Parts should be designed so that threads terminate a minimum of 0.8 mm (1/32 in) from the end (see **Figures 37** and **38**). This practice helps reduce fretting from repeated assembly and disassembly, and eliminates compound sharp corners at the end of the thread. It also prevents cross-threading of finer threads when assembled to a mating metal thread.

Threads — Effect of Creep

When designing threaded assemblies of metal to plastic, it is preferable to have the metal part external to the plastic. In other words, the male thread should be on the plastic part. However, in a metal/plastic assembly, the large difference in the coefficient of linear thermal expansion between the metal and plastic must be carefully considered. Thermal stresses created because of this difference will result in creep or stress relaxation of the plastic part after an extended period of time if the assembly is subject to temperature fluctuations or if the end use temperature is elevated. If the plastic part must be external to the metal, a metal backup sleeve may be needed as shown in **Figure 39**.

Figure 37. Correct Termination of Threads

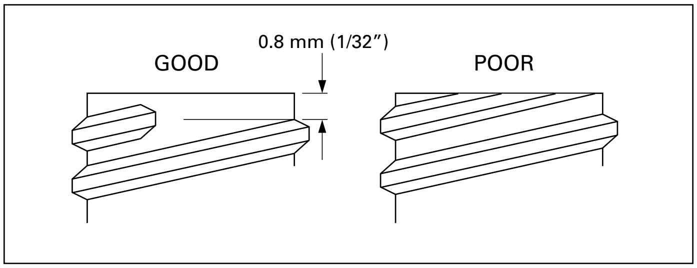


Figure 38. Suggested End Clearance on Threads

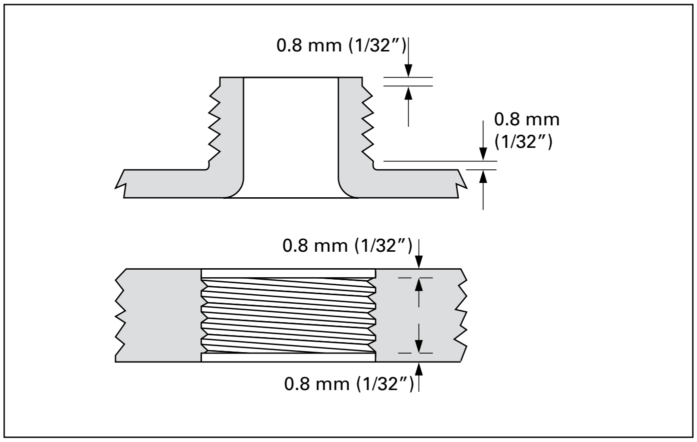
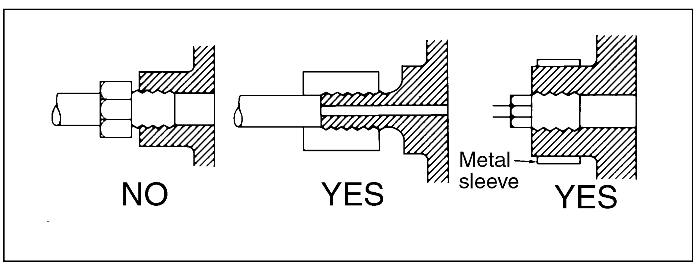


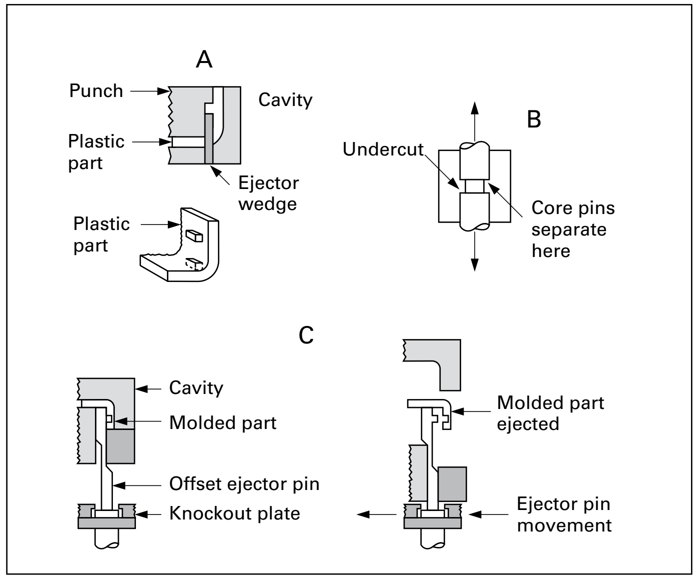
Figure 39. Suggestions for Designing Threaded Assemblies of Metal to Plastic



Undercuts

Undercuts are formed by using split cavity molds or collapsible cores. Internal undercuts can be molded by using two separate core pins, as shown in **Figure 40 B**. This is a very practical method, but flash must be controlled where the two core pins meet. **Figure 40 A** shows another method using access to the undercut through an adjoining wall. Offset pins may be used for internal side wall undercuts or holes (see **Figure 40 C**). The above methods eliminate the need for stripping and the concomitant limitation on the depth of the undercut.

Figure 40. Undercuts



Molded-in Inserts

Adding ribs, bosses or molded-in inserts to various part designs can solve some problems but may create others. Ribs may provide the desired stiffness, but they can produce warpage. Bosses may serve as a suitable fastening device for a self-tapping screw, but they can cause sink marks on the surface opposite the boss. Molded-in inserts may enable the part to be assembled and disassembled many times without loss of threads. Considering these possible problems, the appropriate question is, when should molded-in inserts be used? The answer is the same for ribs and bosses as well. Inserts should be used when there is a functional need for them and when the additional cost is justified by improved product performance. There are four principal reasons for using metal inserts:

- To provide threads that will be serviceable under continuous stress or to permit frequent part disassembly (generally, more than 5 times).
- To meet close tolerances on female threads.
- To afford a permanent means of attaching two highly loaded bearing parts, such as a gear to a shaft.
- To provide electrical conductance.

Once the need for inserts has been established, alternate means of installing them should be evaluated. Rather than insert molding, press or snap-fitting or ultrasonic insertion should be considered. The final choice is usually influenced by the total production cost. However, possible disadvantages of using molded-in inserts other than those mentioned previously should be considered:

- Inserts can "float," or become dislocated, causing damage to the mold.
- Inserts are often difficult to load, which can prolong the molding cycle.
- Inserts may require preheating.
- Inserts in rejected parts are costly to salvage.

The most common complaint associated with insert molding is delayed cracking of the surrounding plastic because of molded-in hoop stress. The extent of the stress can be determined by checking a stress/strain diagram for the specific material. To estimate hoop stress, assume that the strain in the material surrounding the insert is equivalent to the mold shrinkage. Multiply the mold shrinkage by the flexural modulus of the material (shrinkage times modulus equals stress

Since filled resins offer lower mold shrinkage than their base resins, they have been used successfully in appropriate applications. Their lower elongation is offset by a typical mold shrinkage range of 0.002 to 0.005 mm/mm (in/in). Although the knit lines of heavily filled resins may have only 60% of the strength of an unfilled material, the addition of a rib can substantially increase the strength of the boss (see **Figure 41**).

Part Design for Insert Molding

Designers need to be concerned about several special considerations when designing a part that will have molded-in inserts:

- Inserts should have no sharp corners. They should be round and have rounded knurling. An undercut should be provided for pullout strength (see **Figure 42**).
- The insert should protrude at least 0.40 mm (0.016 in) into the mold cavity.
- The thickness of the material beneath it should be equal to at least one-sixth of the diameter of the insert to minimize sink marks.
- Inserts should be preheated before molding
- A thorough end-use test program should be conducted to detect problems in the prototype stage of product development. Testing should include temperature cycling over the range of temperatures to which the application may be exposed.

From a cost standpoint-particularly in high-volume, fully automated applications-insert costs are comparable to other post-molding assembly operations. To achieve the optimum cost/performance results with insert molding, it is essential that the designer be aware of possible problems. Specifying molded inserts where they serve a necessary function, along with careful follow-up on tooling and quality control, will contribute to the success of applications where the combined properties of plastics and metals are required.

Figure 41. Boss Design Details for Insert Molding

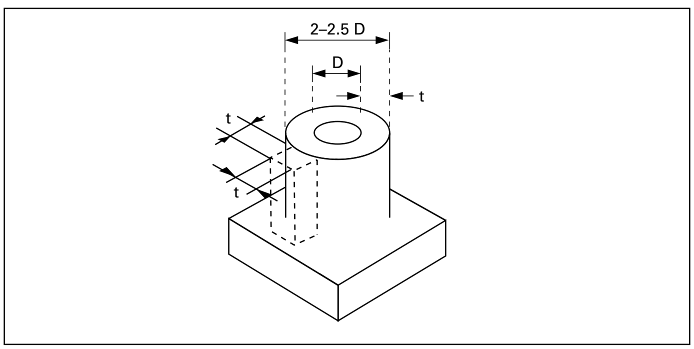
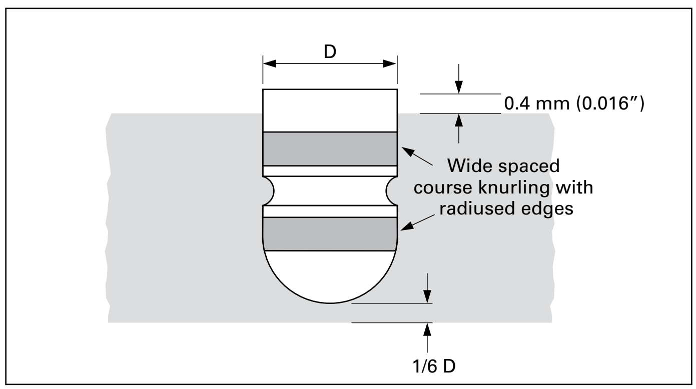


Figure 42. Insert Design Details



Appendix

Appendix A

Design Check List

Part Name ____

Company ____

Print No. ____

Job No. ____

A. PART FUNCTION ____________________________________

B. OPERATING FUNCTIONS	Normal	Max.	Min.
Operating temperature	________	________	________
Service life (hrs)	________	________	________
Applied load (lb torque, etc. describe fully on reverse side) Time on	________	________	________
Duration of load Time off	________	________	________

Other (Impact, Shock, Stall, etc.) ______________________________

____

____

C. ENVIRONMENT Chemical __________ Moisture ______________

Ambient temperature while device not operating ____ Sunlight direct ______Indirect _____

D. DESIGN REQUIREMENTS

Factor of safety ________________Max. Deflection/Sag ___________

E. WEAR CONSIDERATIONS

Mating Material ______________ Surface Finish _________________

Pressure ____

Velocity ____

Rotation or Oscillation _________________________________

Limiting Wear Rate or Wear Volume ___________________________

Appendix B —Stress/Strain Curves as a Function of Temperature in Tension and Compressions

Figure B-1 TP-8054 Stress/Strain in Tension (ISO 527)

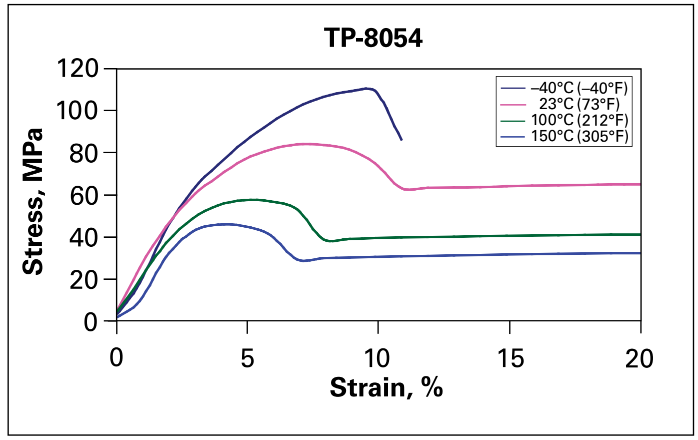


Figure B-2 TP-8395 Stress/Strain in Tension (ISO 527)

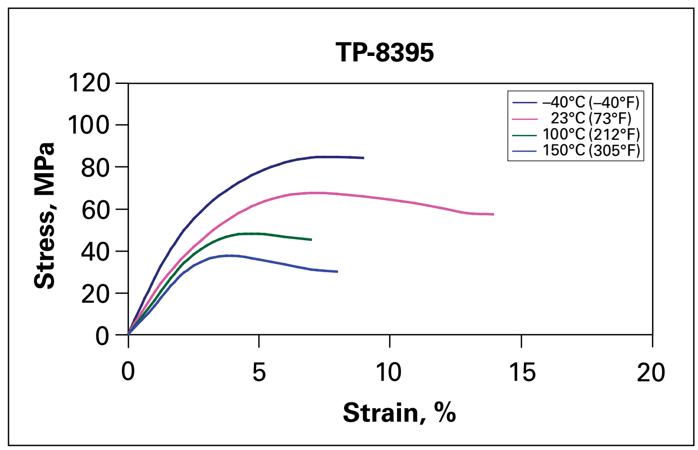


Figure B-3 TP-8212 Stress/Strain in Tension (ISO 527)

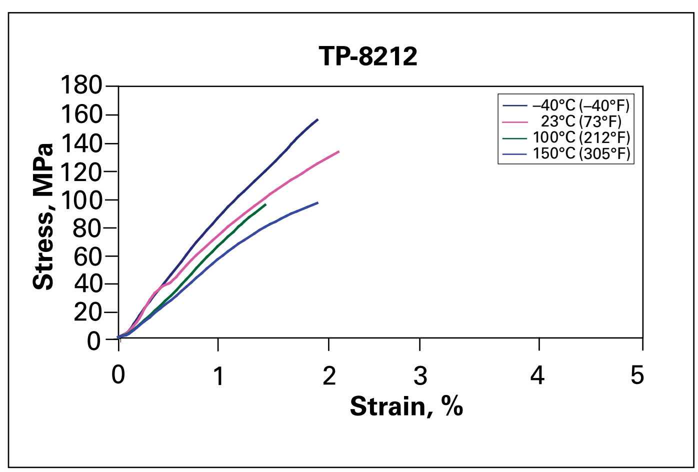


Figure B-4 TP-8130 Stress/Strain in Tension (ISO 527)

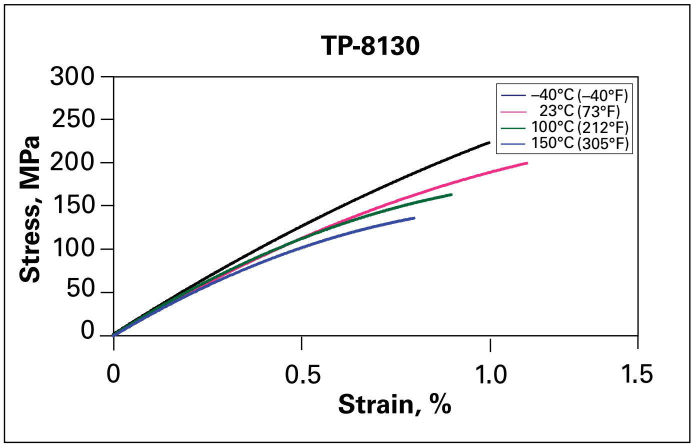


Figure B-7 TP-8792 Stress/Strain in Tension (ISO 527)

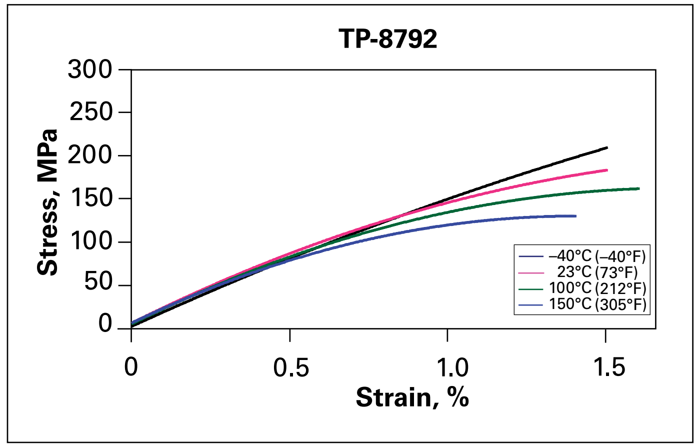


Figure B-5 TP-8311 Stress/Strain in Tension (ISO 527)

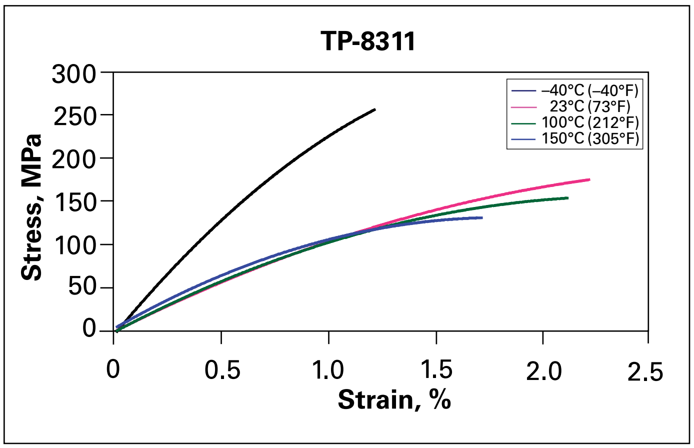


Figure B-8 TP-8054 Stress/Strain in Compression (ISO 604)

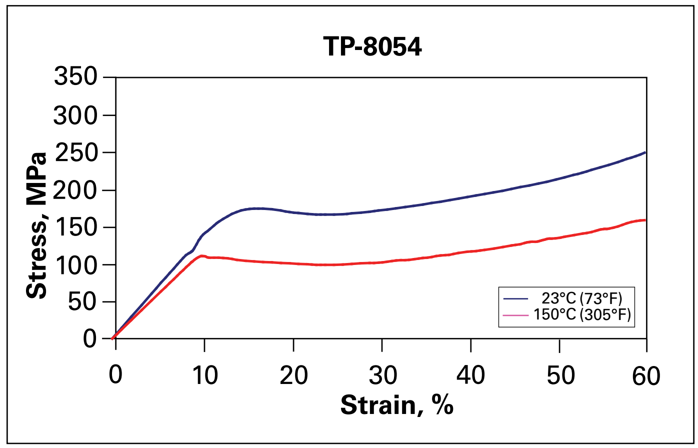


Figure B-6 TP-8549 Stress/Strain in Tension (ISO 527)

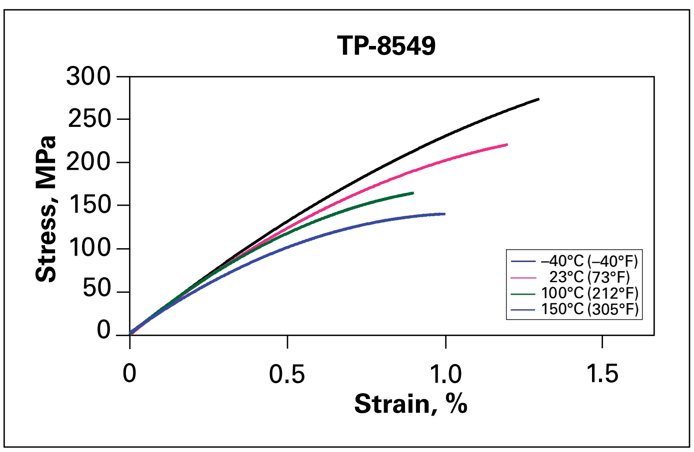


Figure B-9 TP-8395 Stress/Strain in Compression (ISO 604)

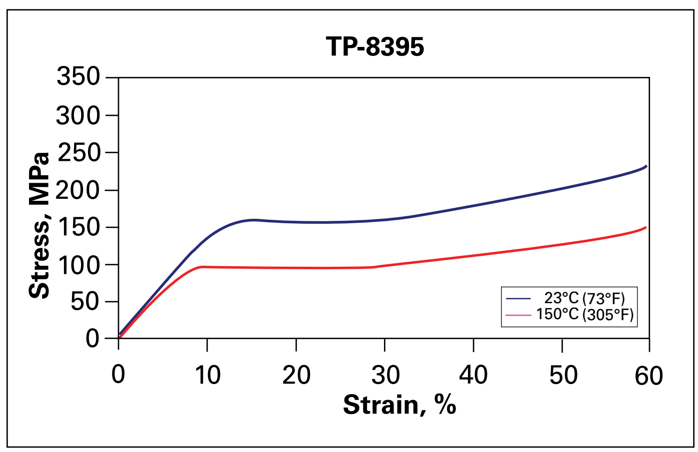


Figure B-10 TP-8212 Stress/Strain in Compression (ISO 604)

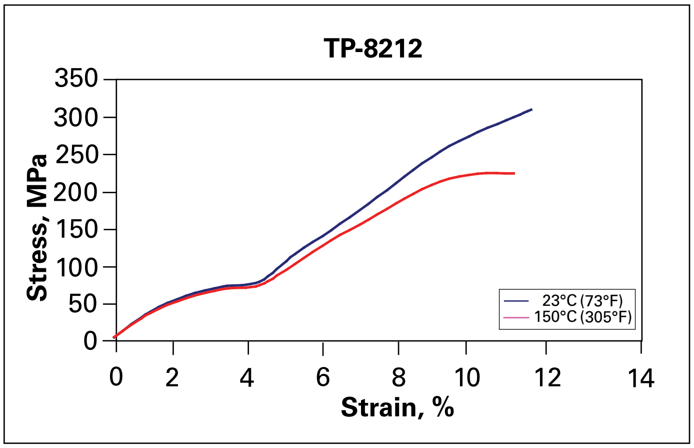


Figure B-11 TP-8130 Stress/Strain in Compression (ISO 604)

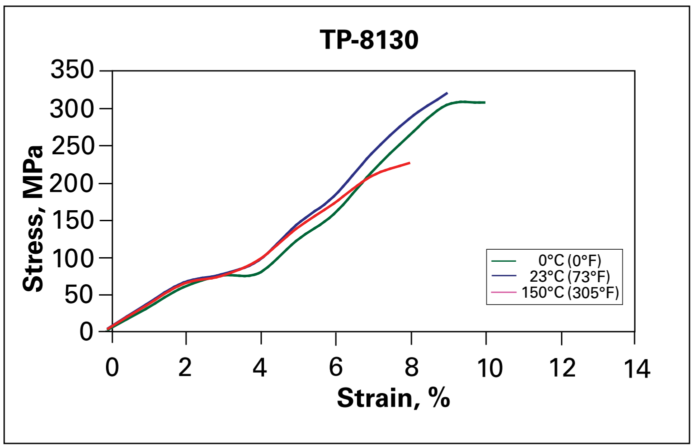


Figure B-12 TP-8311 Stress/Strain in Compression (ISO 604)

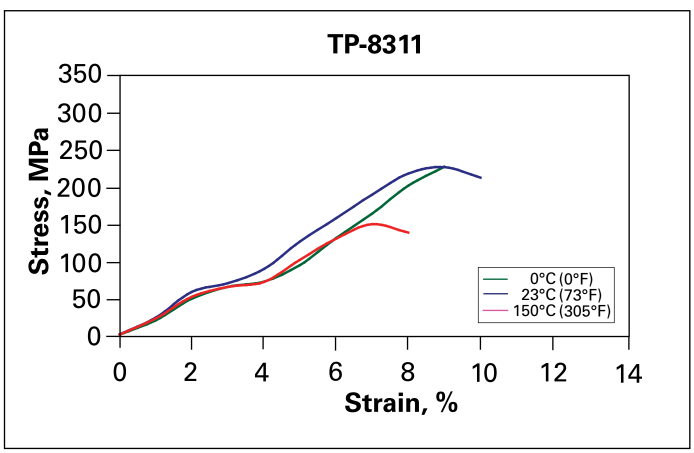


Figure B-13 TP-8549 Stress/Strain in Compression (ISO 604)

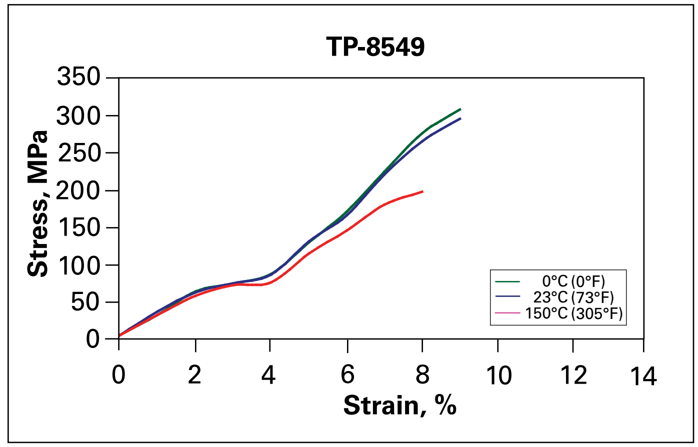
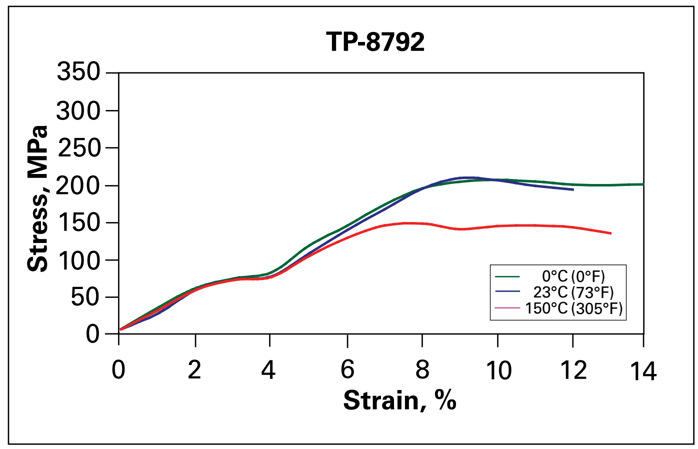


Figure B-14 TP-8792 Stress/Strain in Compression (ISO 604)



Appendix C — Flexural Creep

Figure C-1 TP-8054 Flexural Creep (ASTM D2990)

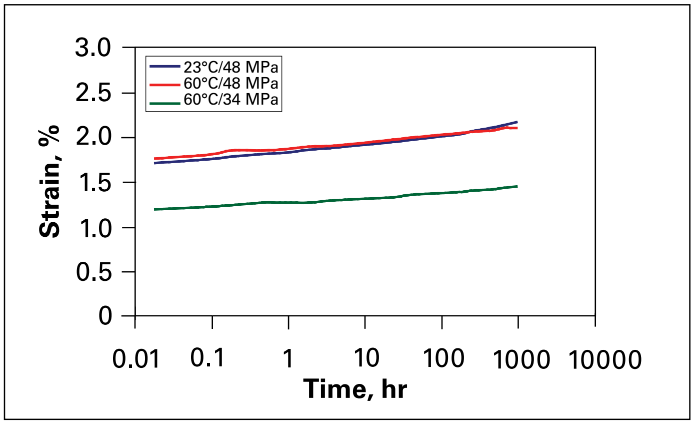


Figure C-2 TP-8395 Flexural Creep (ASTM D2990)

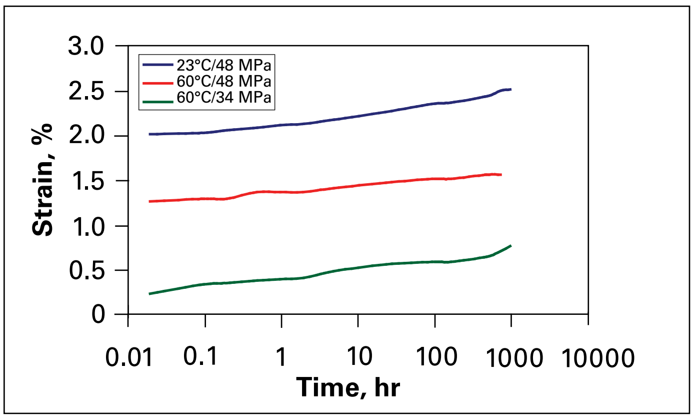


Figure C-3 TP-8212 Flexural Creep (ASTM D2990)

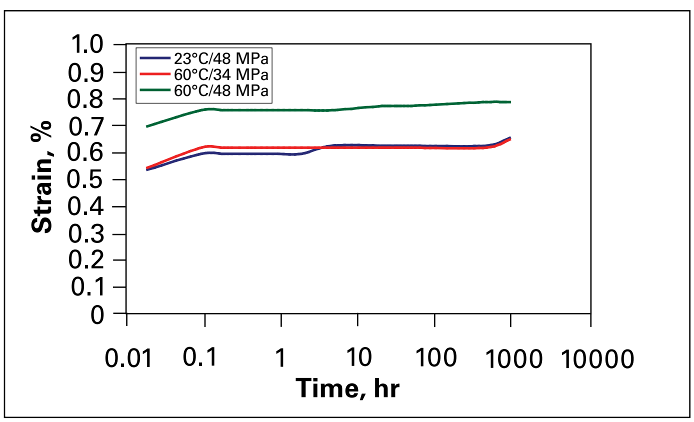


Figure C-4 TP-8130 Flexural Creep (ASTM D2990)

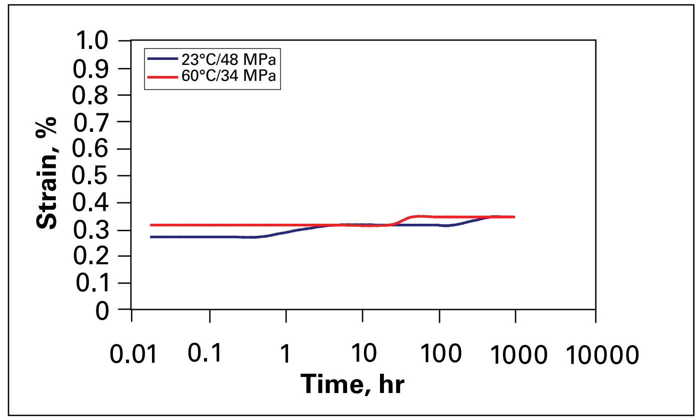


Figure C-5 TP-8311 Flexural Creep (ASTM D2990)

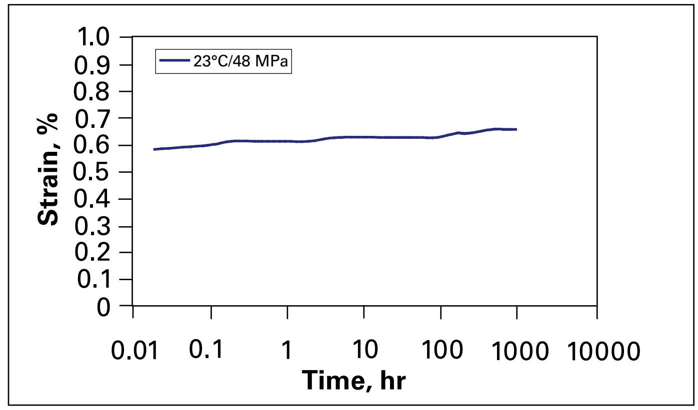


Figure C-6 TP-8549 Flexural Creep (ASTM D2990)

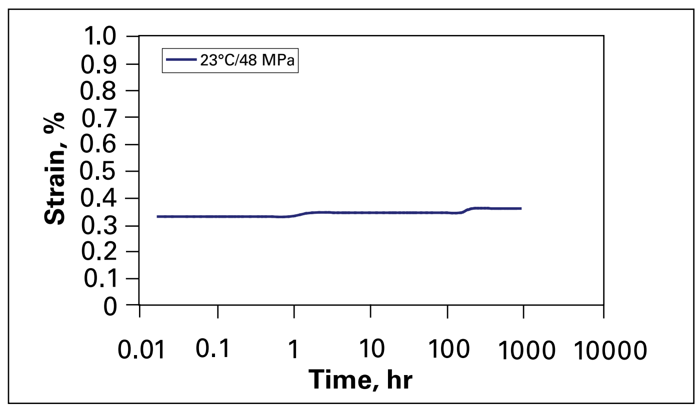
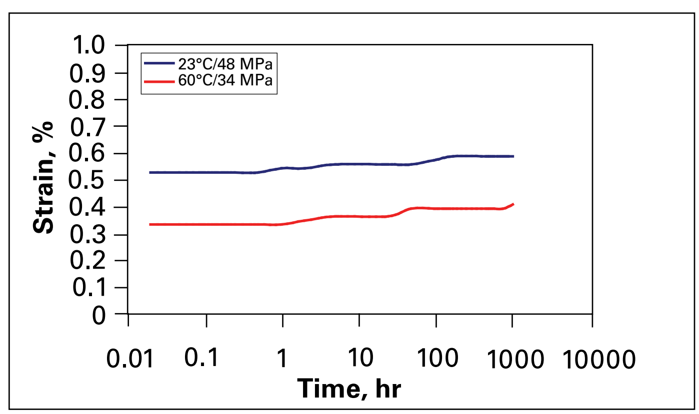


Figure C-7 TP-8792 Flexural Creep (ASTM D2990)



Appendix D — Chemical Resistance Data

TP-8054 Film Exposure

	Property Retention, % at 80°C in H_2SO_4 Solution			
	pH = 2		pH = 3	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	115	120	110	115
Tensile Strength at Break	110	105	100	105
Appearance	No change	No change	No change	No change

TP-8054 Film Exposure

	Property Retention, % at 80°C in HNO_3/H_2SO_4 Solution			
	pH = 2		pH = 3	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	115	115	115	120
Tensile Strength at Break	100	95	95	100
Appearance	No change	No change	No change	No change

TP-8054 Film Exposure

	Property Retention, % at 80°C in HNO_3/H_2SO_4 Solution			
	pH = 2		pH = 3	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	115	115	115	120
Tensile Strength at Break	100	95	95	100
Appearance	No change	No change	No change	No change

TP-8054 Film Exposure

	Property Retention, % at 23°C			
	5% NaCl		5% NaOH	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	110	115	100	—
Tensile Strength at Break	100	105	90	60
Appearance	No change	No change	No change	No change

TP-8054 Film Exposure

	Property Retention, % at 23°C			
	Methanol		Ethanol	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	110	110	110	110
Tensile Strength at Break	110	110	105	110
Tensile Modulus	100	105	105	110
Elongation at Break	105	100	110	105
Appearance	No change	No change	No change	No change

TP-8054 Film Exposure

	Property Retention, % at 40°C in 500 ppb Ozone			
	Amorphous		Crystalline	
	1000 hr	2000 hr	1000 hr	2000 hr
Tensile Strength at Yield	100	105	—	—
Tensile Strength at Break	105	100	100	100
Tensile Modulus	105	100	100	100
Elongation at Break	100	105	100	105
Appearance	No change	No change	No change	No change

Acid Exposure
TP-8054 Test Specimen Exposure

	Property Retention, %	
	19% Nitric Acid 3 weeks 23–60°C	98% Phosphoric Acid 3 weeks 23–214°C
Tensile Strength at Yield	96	88
Tensile Strength at Break	100	103
Tensile Modulus	96	65
Elongation at Break	+0.0	–1.0
Appearance	No change	No change

Refrigerant Exposure
TP-8054 Test Specimen Exposure

	Property Retention, % Oil/Refrigerant = 10/1 wgt Oil: Kyoseki FLEOL F-32 Refrigerant: R-134 A (CH_2FCF_3) 100 hr at 60°C
Tensile Strength at Yield	110
Tensile Strength at Break	100
Tensile Modulus	100
Elongation at Break	60
Weight Change	+0.2
Appearance	No change

Also considered to have excellent resistance to other refrigerants including 11, R-113 and R-22

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