DuPont™ Tefzel®

fluoropolymer resin

Properties Handbook

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Introduction

DuPont™ *Tefzel*® fluoropolymers are melt-processible thermoplastics. They are part of the DuPont family of fluorine-based products that includes *Teflon*® PTFE, *Teflon*® FEP, and *Teflon*® PFA fluoropolymer resins.

This handbook presents data for engineers and others involved in materials selection and product design. It contains detailed information for the evaluation of *Tefzel*® in electrical, mechanical, and chemical applications.

All properties presented in this handbook should be considered as typical values and are not to be used for specification purposes. The age of this data varies, ranging in origin from the 1970s to the 1990s.

A variety of natural and reinforced compositions is available, permitting the selection of resins based on specific applications or processing needs.

A continuing program of resin development is being conducted by DuPont. For additional technical data, information about the current line of *Tefzel*® compositions or design assistance for a particular application, please contact the DuPont office listed on the back cover.

Commercially Available DuPont™ *Tefzel*® Fluoropolymers

Tefzel® ETFE Grade	Resin Characteristics	Applications
200	General-purpose fluoropolymer resin with intermediate flow rate. Recommended upper service temperature is 150°C.	• Electrical sleeving, coil forms, sockets, connectors and switches.
207	Special-purpose fluoropolymer resin with a higher flow rate but still maintains a service temperature of 150°C.	• Ideal for injection molding and thin wall extrusion.
210	Special-purpose fluoropolymer resin with a higher flow rate and lower maximum service temperature.	• Uniquely suitable for high speed processing, especially for extruded coatings and injection molding of slender, thin-walled or intricate shapes.
280	Premium fluoropolymer resin with a relatively low flow rate, a greatly enhanced flex life, and a resistance to environmental stress.	• Components, linings and molded parts for use in unusually extreme thermal, mechanical, and chemical environments.
750	Higher temperature rating, more flexible.	• Appliance wire • Motor lead wire • Wire and cable
2195	Free-flowing powder, with controlled particle size, shape, and size distribution.	• Pump housings, vessels, columns, elbows, tees, and pipe sections with unusual shapes.
HT-2004	Glass-fiber reinforced resin for enhanced mechanical properties.	• Injection-molded articles with unique mechanical properties.
HT-2127	Provides the general characteristics of other *Tefzel*® resins while providing greater flexibility, improved retention of tensile properties at elevated temperatures, reduced flammability and long life at higher temperatures.	• Compact wire and cable constructions for service in demanding environments – airframe wiring.
HT-2160	Static dissipating semiconductive resin.	• Extruded tubing, pipe and other profiles for hose. • Injection and blow-molded articles requiring superior electrical, chemical, and thermal properties.

Commercially Available DuPont™ *Tefzel*® Fluoropolymers *(continued)*

Tefzel® ETFE Grade	Resin Chracteristics	Applications
HT-2170	Improved stress crack resistance and flexibility (when compared with other static-dissipating *Tefzel*® ETFE resins).	• Extruded tubing, pipe, and other profiles for hose. • Linings of components used in the chemical processing industries. • Industrial film. • Injection and blow-molded articles requiring superior electrical, chemical, and thermal properties and stress crack resistance.
HT-2181	General-purpose resin. Intermediate flow rate.	• Films • Tubing • Injection-molded articles or linings • Wire and cable
HT-2183	Improved stress crack resistance version of HT-2181.	• Tubing • Injection-molded articles or linings • Wire and cable
HT-2185	Higher flow rate version of HT-2181.	• Films • Tubing • Injection-molded articles or linings
HT-2202	Special-purpose resin available designed to promote adhesion between polyamide resins and ETFE resins.	• Tubing, valves, containers, and fasteners. • Battery or instrument components.
Powder Resins	Five grades are available covering a broad range of MFRs and particle sizes. The lower MFR resin provides a higher degree of stress crack resistance, while the higher MFR resin is easier to process.	• Ideal for when materials must be dispersed in an ETFE matrix. Materials can be well dispersed in the powder and then either compression molded or melt mixed for additional processing.

Other product grades are also available for special processing needs. *Tefzel*® film is available in a wide range of thicknesses for electrical, chemical, and release applications. These include:

Type LZ: General purpose film

Type CLZ: Treated one side for improved cementability

Type CLZ-20: Treated both sides for improved cementability

Specifications

The ASTM material specification covering *Tefzel*® is D3159.

Tefzel® is also called out in various industrial and military specifications for tubing, molded parts, and film, as well as numerous wire and cable applications.

Description

Tefzel® can best be described as a rugged thermoplastic with an outstanding balance of properties. Mechanically, it is tough, has medium stiffness (1,170 MPa, 170,000 psi), impact, and abrasion resistance. Flex life depends upon the grade used, with *Tefzel*® 280 being higher than the other grades. The glass reinforced compound (*Tefzel*® HT-2004) has higher tensile strength (83 MPa, 12,000 psi), stiffness (6,555 MPa, 950,000 psi), and creep resistance than unfilled grades. However, it is still tough and impact resistant.

Tefzel® is typically considered to have a no load continuous use temperature of 150°C (302°F). In certain specific applications, *Tefzel*® can have an upper service temperature in excess of 230°C (392°F). See page 13 for a more complete discussion of thermal rating.

Tefzel® is weather resistant, inert to most solvents and chemicals, and is hydrolytically stable. It has substantially better resistance to radiation than *Teflon*® but is not immune to damage by long-term exposure to gamma radiation, especially at elevated temperatures. Where specific radiation requirements must be met, adequate testing of the proposed application in the radiation environment must be carried out to establish the suitability of *Tefzel*® for this application.

Electrically, *Tefzel*® is an excellent low-loss dielectric, with a uniformity of electrical properties not normally found with other thermoplastics.

A list of typical properties of *Tefzel*® is shown in **Table 1**.

Tefzel® can be extruded or injection molded easily, using conventional techniques, and thus presents no unusual operator training problems. Corrosion resistant equipment is recommended for extended production runs. Electrically heated dies are recommended for injection molds.

Tefzel® can perform successfully in applications where other materials are lacking in mechanical toughness, broad thermal capability, ability to meet severe environmental conditions, or limited by fabricating problems.

As is the case with all new developments, a thorough prototype and test program is recommended to ensure successful performance of *Tefzel*® compositions in specific applications.

Table 1
Typical Properties of DuPont™ *Tefzel*® Fluoropolymers

Property	ASTM Method	Units	*Tefzel*® Grade 210	200	280
Mechanical					
Melt Flow Rate	D3159	g/10 min	23	7	4
Ultimate Tensile Strength, 23°C (73°F)*	D638	MPa (psi)	40 (5,800)	46 (6,500)	47 (6,700)
Ultimate Elongation, 23°C (73°F)*	D638	%	150–300	150–300	150–300
Compressive Strength, 23°C (73°F)**	D695	MPa (psi)	17 (2,500)	17 (2,500)	17 (2,500)
Flexural Modulus	D790	MPa (psi)	1,200 (170,000)	1,200 (170,000)	1,200 (170,000)
Impact Strength, 23°C (73°F)	D256	J/m (ft·lb/in)	no break no break	no break no break	no break no break
Hardness, Durometer, Shore D	D2240		63	67	72
Coefficient of Friction, Metal/Film	D1894		0.23	0.23	0.23
Deformation Under Load, 23°C (73°F), 1000 psi, 24 hr	D621	%	0.2	0.3	0.2
Linear Coefficient of Expansion	E831				
0–100°C		mm/mm·°C x 10^{-5}	12.6	13.1	13.3
100–150°C			17.6	18.5	20.9
150–200°C			22.3	25.2	25.7
32–212°F		(in/in·°F x 10^{-5})	(7.0)	(7.3)	(7.4)
212–302°F			(9.8)	(10.3)	(11.6)
302–392°F			(12.4)	(14.0)	(14.3)
Specific Gravity	D792		1.72	1.71	1.70
Water Adsorption, 24 hr	D570	%	0.007	0.007	0.005
Electrical					
Surface Resistivity	D257	ohm·sq	$>10^{15}$	$>10^{16}$	$>10^{16}$
Volume Resistivity	D257	ohm·cm	$>10^{17}$	same	same
Dielectric Strength, 23°C (73°F)	D149				
0.25 mm (10 mil)		kV/mm (V/mil)		64 (1,600)	64 (1,600)
3.20 mm (126 mil)		kV/mm (V/mil)		15 (370)	15 (370)

*Actual value depends on test specimen and test conditions.
**Failure defined as stress at 5% strain.

(continued)

Table 1
Typical Properties of DuPont™ *Tefzel®* Fluoropolymers *(continued)*

Property	ASTM Method	Units	*Tefzel®* Grade 210	*Tefzel®* Grade 200	*Tefzel®* Grade 280
Dielectric Constant, 22°C (72°F)	D1531				
1 kHz			←	2.60	→
10 kHz				2.60	
100 kHz				2.60	
1 MHz				2.59	
100 MHz				2.44	
1 GHz				2.33	
3 GHz				2.31	
13.6 GHz			←	2.28	→
Dissipation Factor, 22°C (72°F)	D1531				
1 kHz			←	0.0007	→
10 kHz				0.0011	
100 kHz				0.0023	
1 MHz				0.0070	
100 MHz				0.0230	
1 GHz				0.0172	
3 GHz				0.0119	
13.6 GHz			←	0.0073	→
Arc Resistance	D495	seconds	—	122	—
Thermal					
Melting Point	DTA	°C	←	255–280	→
	D3418	(°F)	←	(491–536)	→
Heat of Fusion	DSC	kJ/kg	46.7	50.7	43.8
	D3417	(Btu/lb)	(20.1)	(21.8)	(18.8)
Specific Heat	DSC	kJ/kg·K			
25°C (77°F)		cal/g·°C	←	0.25	→
100°C (212°F)				0.30	
150°C (302°F)				0.34	
300°C (572°F) (melt)			←	0.38	→
Heat of Combustion	D240	MJ/kg		13.7	
		(Btu/lb)		(5,900)	
Thermal Conductivity		W/m·K		0.24	
		(Btu·in/h·ft^2·°F)		(1.65)	
Limiting Oxygen Index (LOI)	D2863	%	30–32	30–32	30–32
Heat Deflection Temperature	D648	°C (°F)			
455 kPa (66 psi)			←	81 (177)	→
1620 kPa (264 psi)			←	51 (123)	→
Continuous Service Temperature		°C	135	150*	150*
		(°F)	(275)	(302)	(302)

*See page 13 for a more complete discussion of Thermal Rating.

Mechanical Properties

Strength and Stiffness

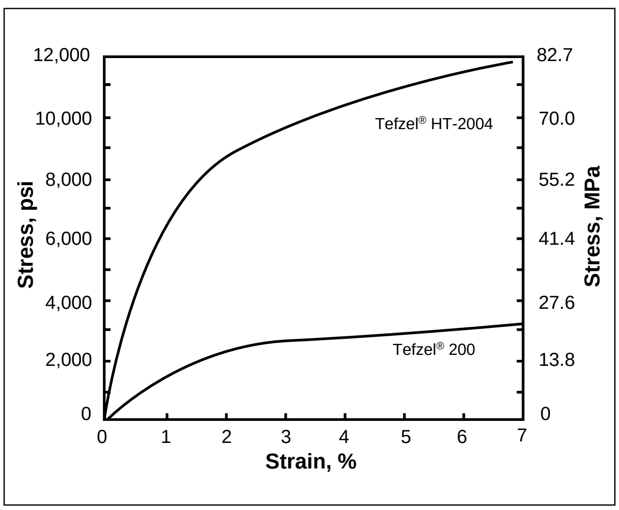
Tefzel® is less dense, tougher, stiffer, and exhibits a higher tensile strength and creep resistance than *Teflon*® PTFE and *Teflon*® FEP fluoropolymer resins. It is, however, similarly ductile. *Tefzel*® compositions display the relatively nonlinear stress-strain relationships characteristic of nearly all ductile materials.

Stress/Strain in Tension and Compression

Figures 1 and **2** show stress vs. strain for *Tefzel*® 200 and *Tefzel*® HT-2004, at room temperature, in both tension and compression. Because of the nonlinear character of the curves beyond approximately a 1% strain, calculation of a corresponding stress based on tangent or secant (1% offset) modulus would be inaccurate.

For this reason, it is recommended that if the calculated strain exceeds 1%, the stress value should be read from the curve. For longer-term strain calculations, the apparent modulus procedure should be used as presented.

Figure 1. Tensile Stress vs. Strain



Tensile Strength vs. Temperature

Figure 3 shows the effect of temperature on tensile strength for *Tefzel*® 200 and *Tefzel*® 280. The effect of temperature on ultimate elongation is shown in **Figure 4**. These measurements were made on 5" x 0.5" x 0.125" injection molded tensile bars. Thinner test specimens will result in slightly higher ultimate elongation values.

The effect of temperature on tensile modulus is shown in **Figure 5**.

Figure 2. Compressive Stress vs. Strain

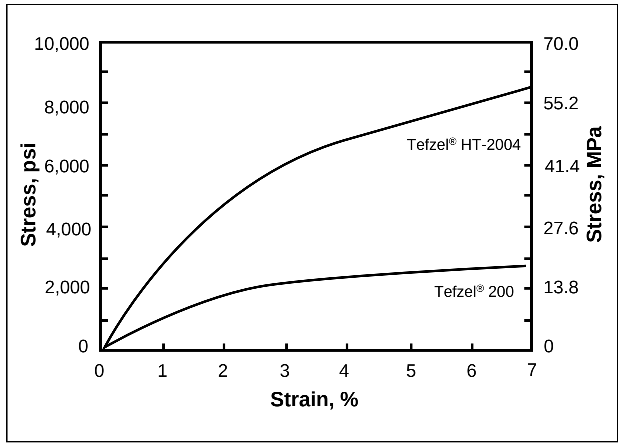


Figure 3. Tensile Strength vs. Temperature

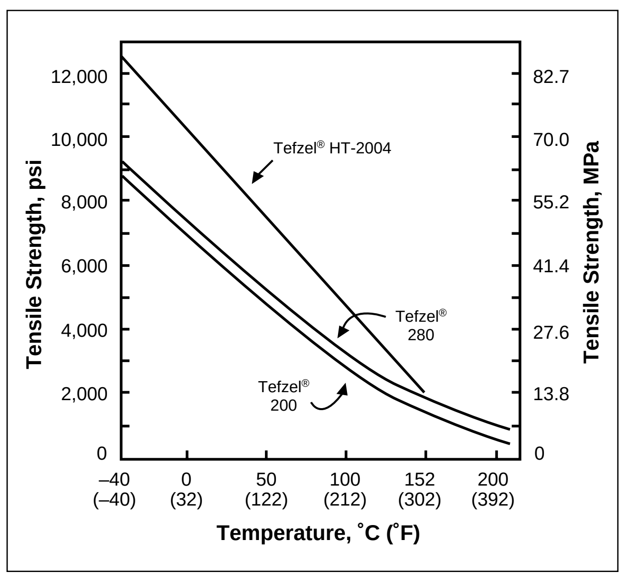


Figure 4. DuPont™ *Tefzel*® 200, 280, and HT-2004—Ultimate Elongation vs. Temperature, 5" x 0.5" x 0.125" Injection Molded Bar

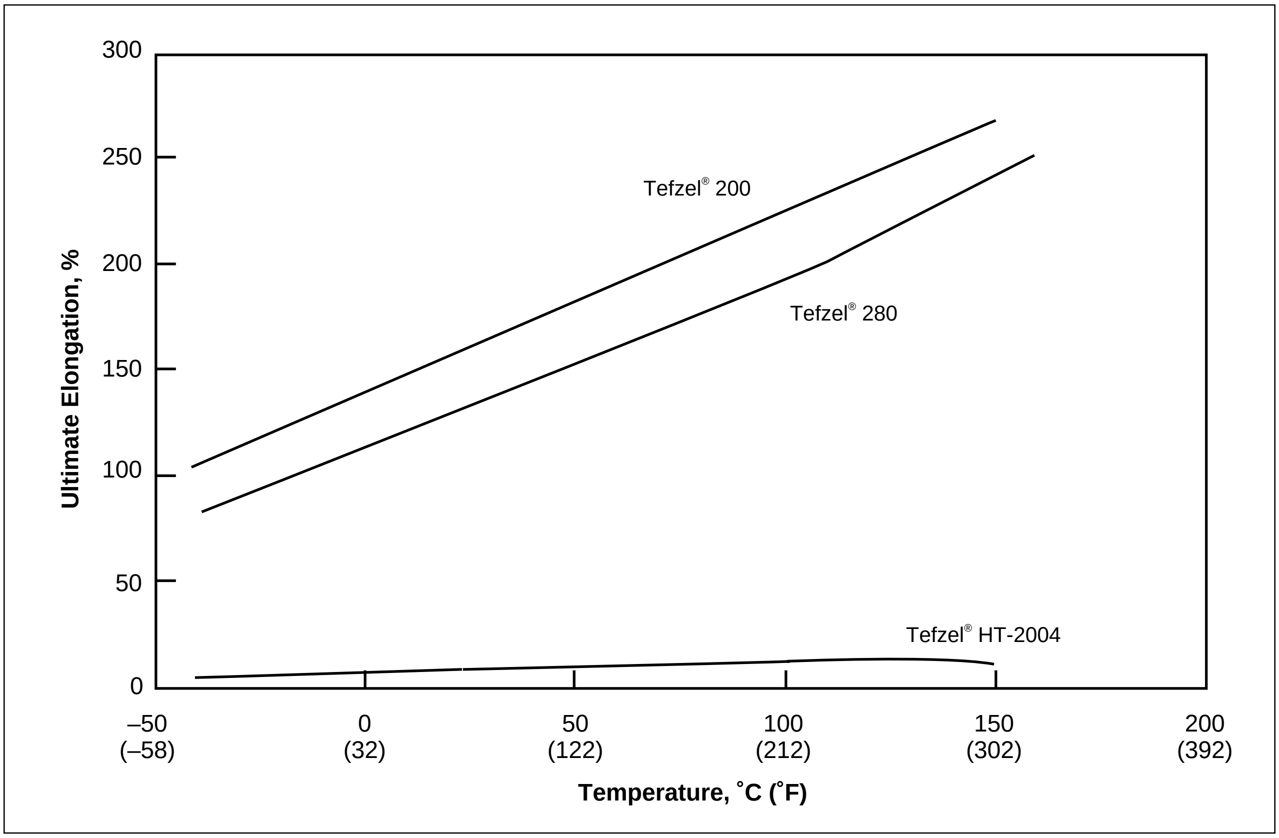
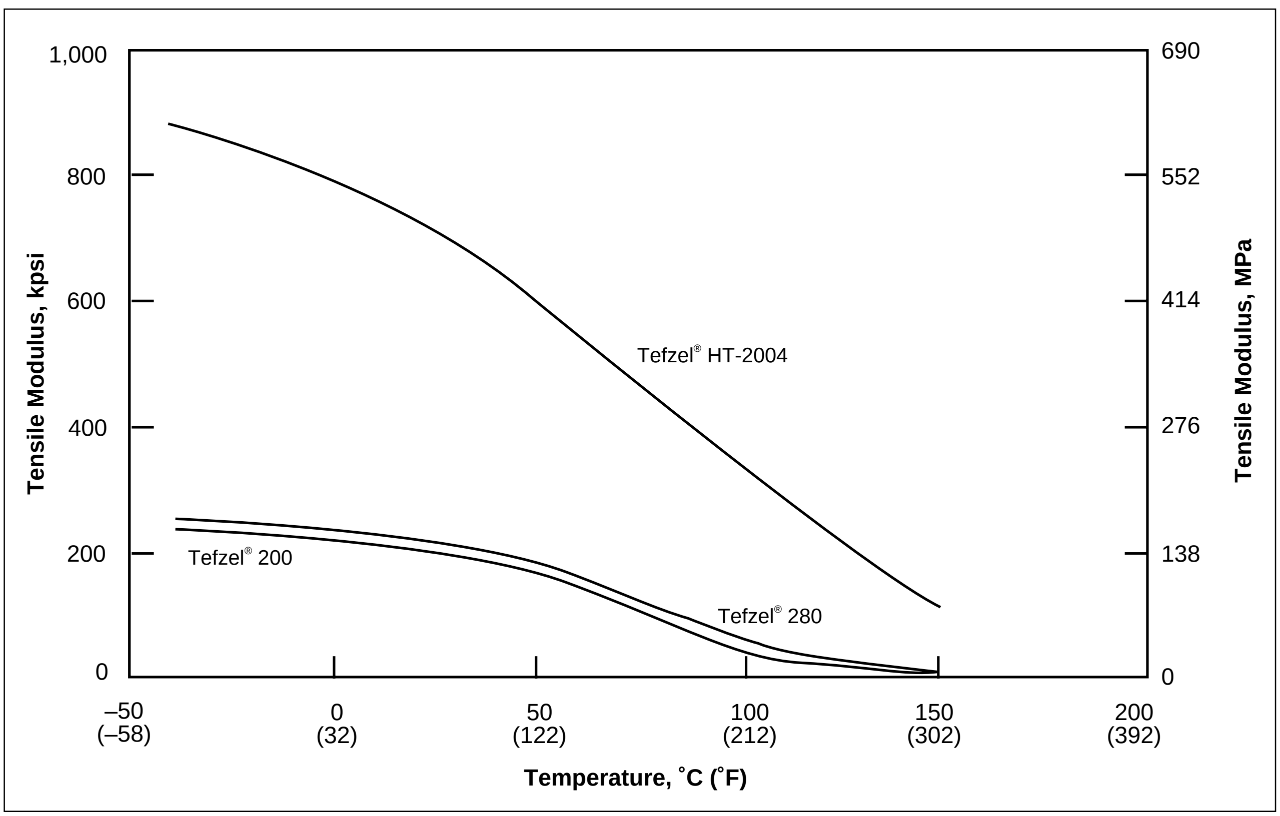


Figure 5. DuPont™ *Tefzel*® 200, 280, and HT-2004—Tensile Modulus vs. Temperature, 5" x 0.5" x 0.125" Injection Molded Bar



Glass Fiber Orientation in Molded Structures

Glass fibers in an injection molded part tend to line up parallel to the lines of flow in filling the mold. This produces nonisotropic strength properties in the part. **Table 2** shows that the tensile strength of *Tefzel*® HT-2004 measured perpendicular to fiber orientation is 70–75% of that parallel to orientation. Thus, a design safety factor is suggested to recognize this phenomenon.

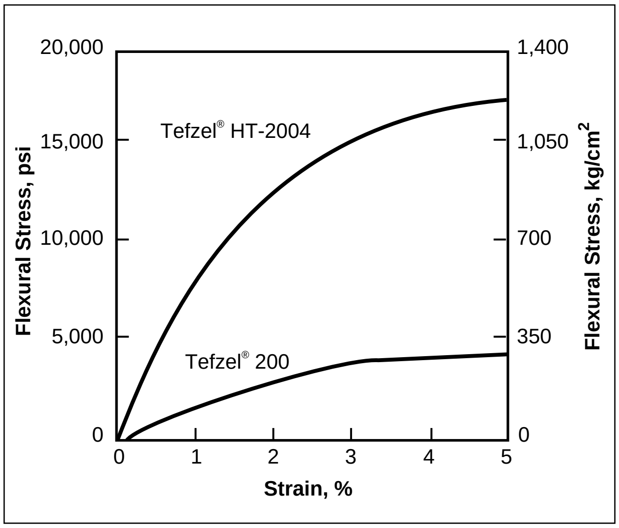
Table 2
Effects of Orientation of Glass Fibers on Tensile Properties of DuPont™ *Tefzel*® HT-2004

Parallel to Glass		Perpendicular to Glass	
Tensile Strength	Elongation	Tensile Strength	Elongation
82.7 MPa (12,000 psi)	8%	57.6 MPa (8,360 psi)	8%

Flexural Properties

The relationship between flexural stress and strain is shown in **Figure 6**.

Figure 6. Flexural Stress vs. Strain—*Tefzel*® 200 and HT-2004. ASTM D790; Room Temperature 23°C (73°F); Span 3" (76 mm); Specimens 0.5" (13 mm) Wide, 0.175" (4 mm) High



Flexural Modulus vs. Temperature

The effect of temperature on flexural modulus, or stiffness, is shown in **Figure 7**.

Figure 7 shows that stiffness decreases significantly as environmental temperature increases for both *Tefzel*® 200 and the glass filled *Tefzel*® HT-2004. However, the glass filled *Tefzel*® retains significant stiffness even at the upper use temperature. When designing parts, these changes with temperature must be taken into consideration in order to achieve the desired functionality.

Creep, Apparent Flex Modulus, and Long-Term Strain

As with other plastics, ambient temperatures and duration of load are important to design variables. The usual relationship:

$$\frac{\text{Stress}}{\text{Strain}} = \text{Modulus}$$

applies to short-term loading of an elastic structure. When load is applied, an initial deflection occurs. If the load is not excessive (i.e., for *Tefzel*®, a load producing less than 1% strain), the conventional modulus figure indicates the correct stress-strain relationship, and standard engineering equations may be applied to predict performance.

If, however, the load is maintained continuously, all materials deform or creep, generally at a decreasing rate with time. The "apparent modulus" concept is a way of mathematically describing this creep behavior.

$$\text{Apparent modulus } (E_a) \text{ (after a given time of load application at a given temperature)} = \frac{\text{Stress (fixed value)}}{\text{Total strain (measured after the given time of exposure)}}$$

Most creep occurs within the first year and, therefore, the apparent modulus at 10,000 hours can be used in many calculations involving continuous load (substitute E_a for E).

"Apparent modulus" is a function of temperature and time. **Figure 8** gives the "apparent flexural modulus" of *Tefzel*® HT-2004 at 23°C (73°F) and 100°C (212°F). To approximate apparent modulus at other temperatures, use **Figure 7**, which shows flexural modulus as a function of temperature. For a given use temperature, read the modulus for

Figure 7. DuPont™ *Tefzel*® 200 and HT-2004—ASTM D790; Flex Modulus vs. Temperature, 5" x 0.5" x 0.125" Injection Molded Bars

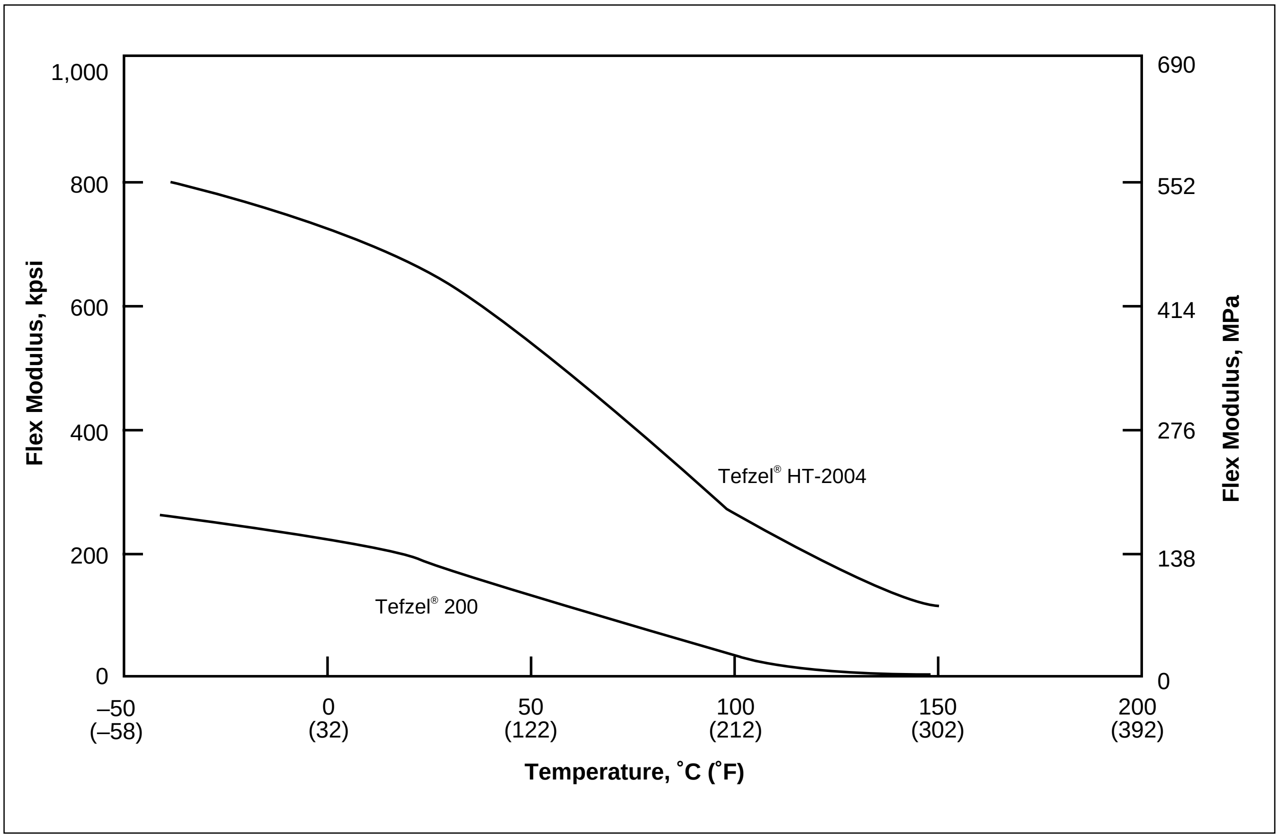
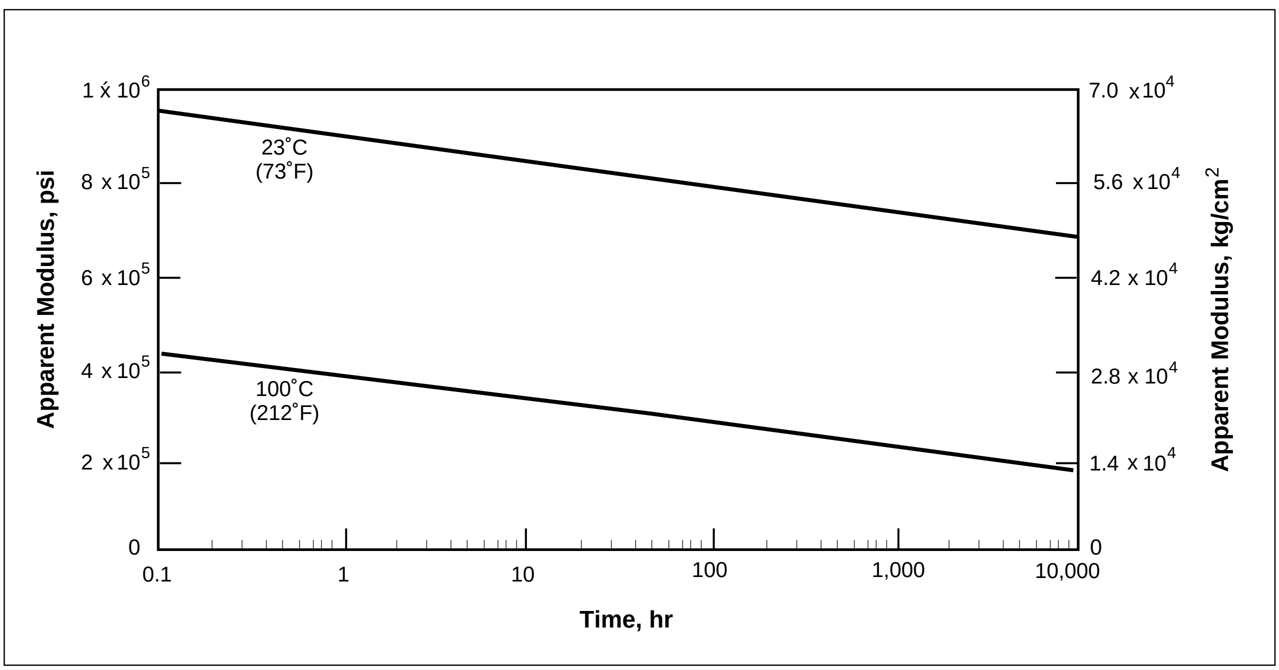


Figure 8. Creep—Apparent Flex Modulus vs. Time and Temperature by ASTM D674, DuPont™ *Tefzel*® HT-2004



Tefzel® HT-2004 from **Figure 7**, using a straight line through it approximating the slopes at 23°C (73°F) or 100°C (212°F) from **Figure 8**. The above discussion is related to flex modulus only. For practical purposes, however, the same procedure normally will give adequate design results for tensile or compressive stresses.

Creep can also be presented to show actual deformation under load vs. time. **Figures 9** and **10** show percent strain at 23°C (73°F) and 100°C (212°F) for *Tefzel*® 200 and *Tefzel*® HT-2004 at two pressures. Curves for *Tefzel*® 280 would be expected to be similar to those of *Tefzel*® 200.

Flex Fatigue

Figure 11 gives the results of rapid flexing tests for *Tefzel*® 200 and *Tefzel*® HT-2004 using a Sonntag flex tester. Although *Tefzel*® HT-2004 has a greater fatigue limit than *Tefzel*® 200, both are quite sensitive to stress levels. For best fatigue performance, stress levels below 20.7 MPa (3,000 psi) and 12.1 MPa (1,750 psi) are suggested for *Tefzel*® HT-2004 and *Tefzel*® 200 respectively. *Tefzel*® 280 would be expected to have a greater flex fatigue limit than *Tefzel*® 200.

Impact Strength

Tefzel® 200 and *Tefzel*® 280 have high impact strength, ranking among the highest of all plastics over a broad temperature range. The low temperature embrittlement point is below –100°C (–148°F). Data showing the effect of temperature are presented in **Table 3**.

Figure 9. DuPont™ *Tefzel*® 200Flexural Creep, 5" x 0.5" x 0.125" Injection Molded Bars

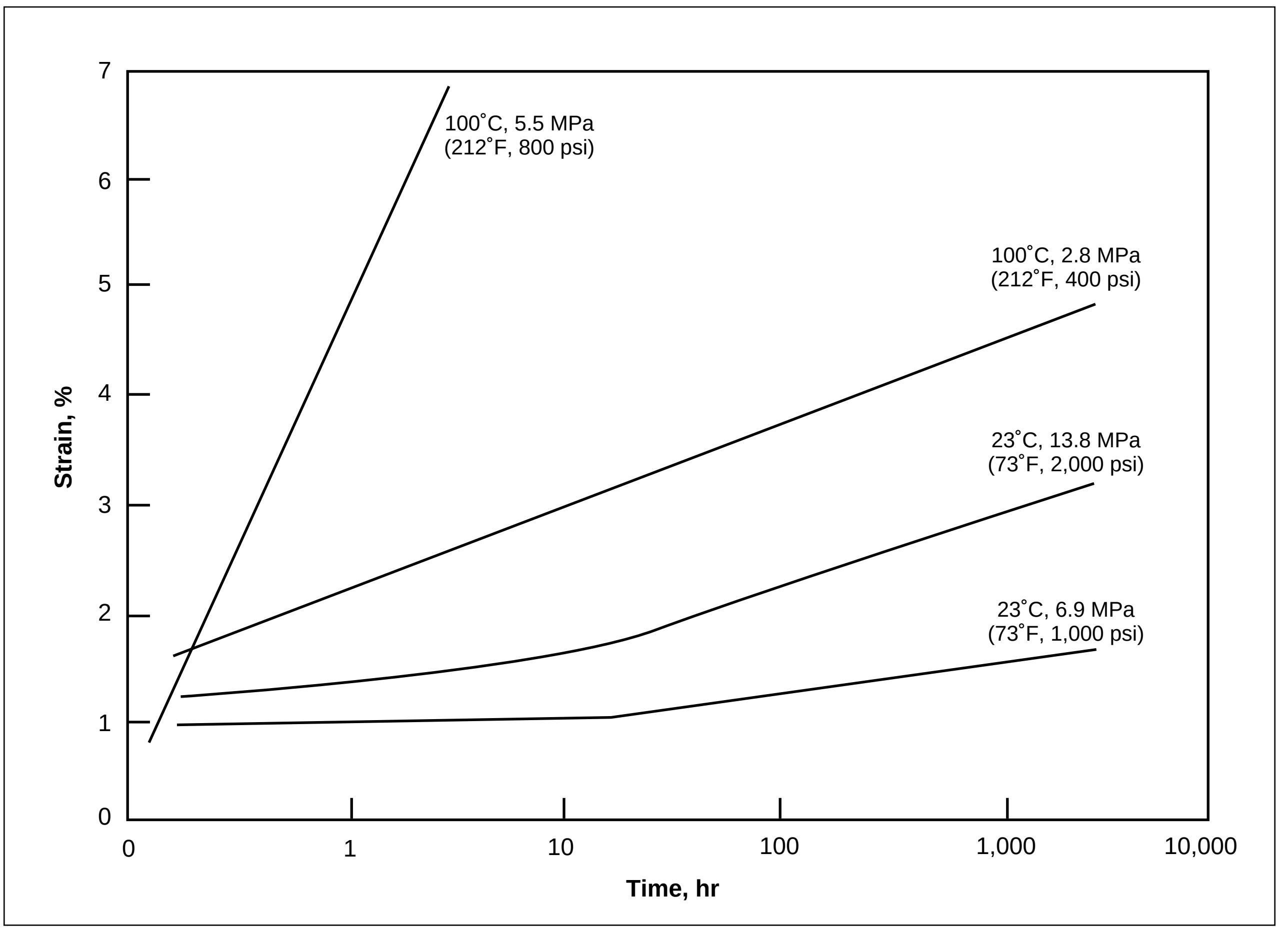


Figure 10. DuPont™ *Tefzel*® HT-2004 Flexural Creep, 5" x 0.5" x 0.125" Injection Molded Bars

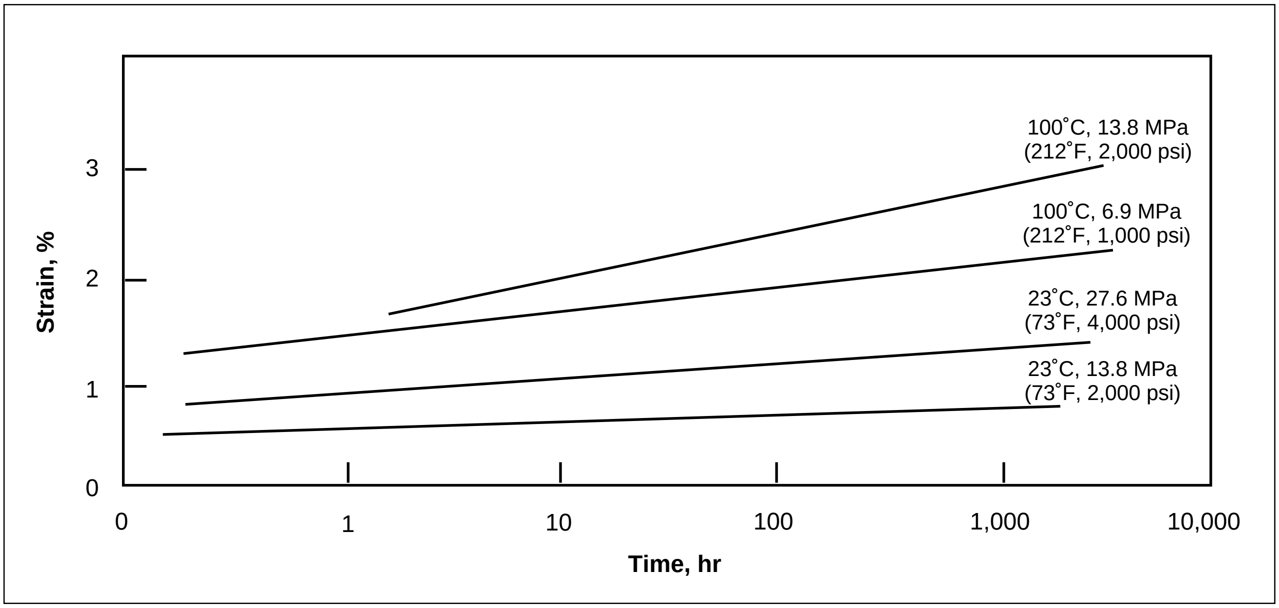


Figure 11. Flex Fatigue of DuPont™ *Tefzel*® 200 and HT-2004, ASTM D671—Tension/Compression; 1,800 Cycles/Minute, 23°C (73°F), 50% RH; Sample Type I, Small

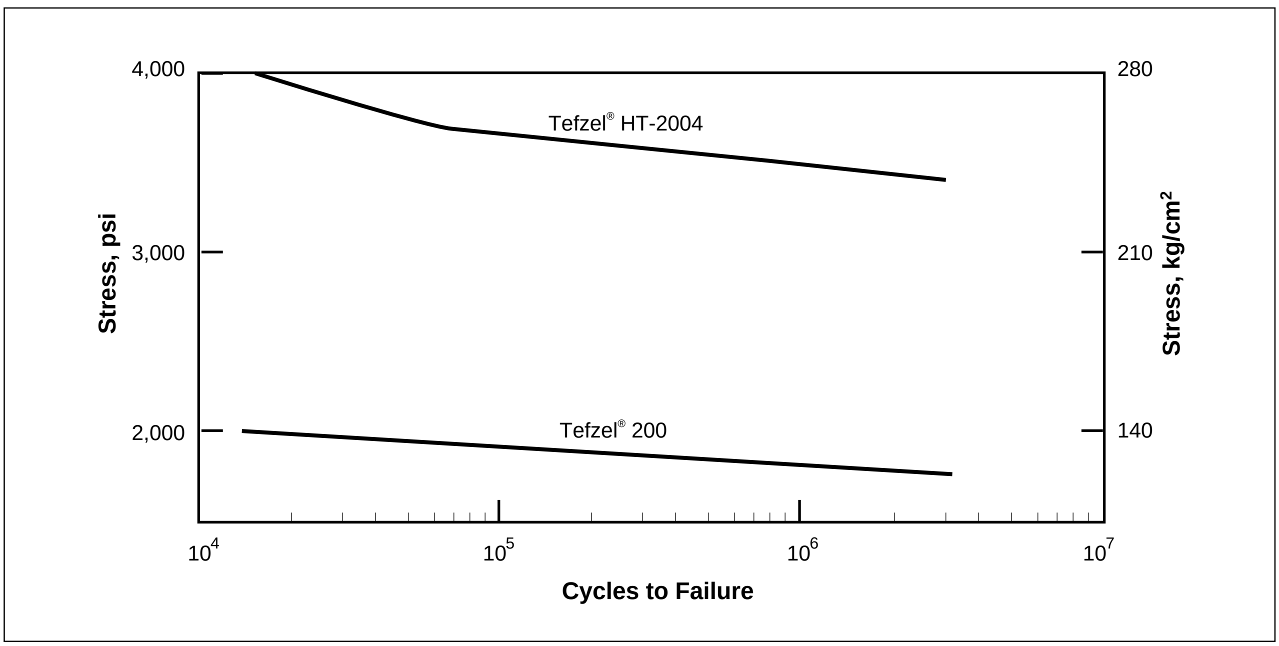


Table 3
DuPont™ *Tefzel*® HT-2004—Effect of Temperature on Izod Impact Strength

	Notched Izod Impact Strength	
Test Temperature	**J/m**	**ft·lb/in**
Tefzel 200		
–60°C (–76°F)	no break	no break
23°C (73°F)	no break	no break
121°C (250°F)	no break	no break
204°C (400°F)	no break	no break
Tefzel 280		
–60°C (–76°F)	no break	no break
23°C (73°F)	no break	no break
121°C (250°F)	no break	no break
204°C (400°F)	no break	no break
Tefzel HT-2004		
–60°C (–76°F)	183.5	3.44
23°C (73°F)	392.5	7.35
121°C (250°F)	no break	no break
204°C (400°F)	no break	no break

Friction and Bearing Wear

Unlike many other polymers, the addition of glass reinforcement improves the frictional and wear properties of *Tefzel*®. For example, the dynamic coefficient of friction (0.69 MPa [100 psi] at 10 ft/min) for *Tefzel*® 200 is 0.4 but drops to 0.3 for *Tefzel*® HT-2004 under these conditions. The wear factor also improves from 6,000 x 10^{-10} to 16 x 10^{-10} in^3·min/ft·lb·hr. These improved frictional and wear characteristics, combined with outstanding creep resistance, suggest that the glass-reinforced resin be favored for bearing applications. *Tefzel*® HT-2004 also appears to be less abrasive on mating surfaces than most glass-reinforced polymers.

The static coefficient of friction for *Tefzel*® HT-2004 is dependent on bearing pressure. This relationship is shown in **Table 4**.

Table 4
Static Coefficient of Friction,
DuPont™ *Tefzel*® HT-2004

Πρεσσυρε		Coefficient of Friction
psi	**MPa**	
10	0.069	0.51
50	0.345	0.38
100	0.69	0.31
500	3.45	0.34

Dynamic friction is dependent on pressure and rubbing velocity (PV). **Figure 12** is a plot of coefficient of friction against PV for *Tefzel*® HT-2004 against steel.

The generation of frictional heat is dependent on coefficient of friction and the PV factor. For *Tefzel*® HT-2004, temperature buildup begins at about a PV of 10,000 and thermal runaway occurs just below a PV of 20,000. The equilibrium bearing temperatures are shown as a function of PV in the upper right-hand corner of **Figure 12**. High wear rates begin at a PV above 15,000.

The rate of wear depends on the type of metal rubbing surface and on other factors such as finish, lubrication, and clearances. Lubrication, harder shaft surfaces, and high finishes all improve wear rates. Minimum diametral clearances of 0.3 to 0.5% are suggested for sleeve bearings.

Table 5 gives wear factors for steel and aluminum. The wear rate of both *Tefzel*® and the metal is much higher for aluminum than for steel. Therefore, if aluminum is the mating metal, an anodized surface is suggested.

The wear factor of *Tefzel*® HT-2004 against steel is about one/tenth that of 33% glass-reinforced nylon.

Figure 12. Frictional Behavior—DuPont™ *Tefzel*® HT-2004 vs. Steel. Thrust-bearing tester, no lubricant, mating surface AISI 1080 steel, 16AA. (Wear transition temperature between 113°–150°C [235°–300°F])

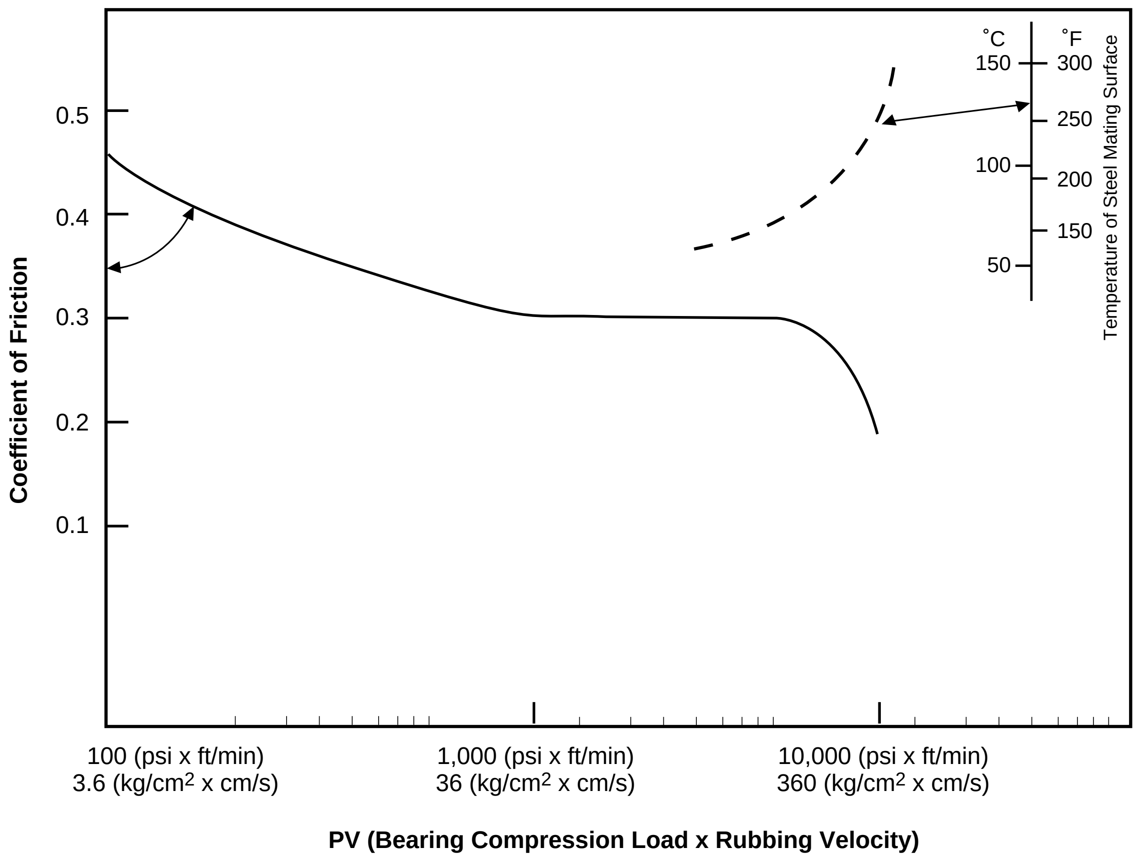


Table 5
DuPont™ *Tefzel*® HT-2004 Bearing Wear Rate[1]

	Pressure		Velocity		Wear Factor K x 10^{-10}	
Mating Surface	**psi**	**MPa**	**ft/min**	**cm/sec**	**Tefzel**	**Metal**
Steel[2]	1,000	6.9	5	2.5	16	4
	1,000	6.9	10	5.1	14	6
	1,000	6.9	15	7.6	19	13
	1,000	6.9	17.5	8.9	30	16
	1,000	6.9	20	10.2	FAIL	—
Aluminum[3]	300	2.07	10	5.1	1,220	1,220
	100	0.69	50	25.4	480	390

[1] Thrust bearing tester, no lubricant, ambient air temperature, metal finish 16 microinches (406 nanometers).
[2] Steel mating surface AISI 1018.
[3] Aluminum mating surface LM24M (English).

Thermal Properties

Tefzel® is a modified copolymer of tetrafluoroethylene and ethylene and, as such, has a melting range rather than a sharp melting point. The melting range of *Tefzel®* is 255°–280°C (491°–536°F). **Table 1** lists the thermal properties of *Tefzel®* 200.

Tefzel® 210 and *Tefzel®* 280 would be expected to be similar.

Temperature Rating

Tefzel® 200 and 280 are typically considered to have a no load continuous use temperature of 150°C (302°F). This continuous use temperature rating is based on 10,000 hour aging tests that involve exposure of standard tensile test specimens and wire insulations to a series of elevated temperatures to determine the rate of change of various physical properties with time. Elongation and tensile strength are properties that change significantly with temperature exposure. These data were fit to an Arrhenius plot (the logarithm of the rate of change of a physical property is a straight line when plotted against the reciprocal of the absolute temperature of exposure). The Arrhenius plots for elongation and tensile strength are presented in **Figures 18** and **19** respectively.

In practice, the upper service temperature of a material depends on the specific nature of the end use application. According to Underwriters Laboratory, fixed property level and percent-of-unaged property level are two end-of-life criteria that appear to have the most significance in relation to end-use applications. **Tables 6a** and **6b** contain estimated upper service temperatures depending on different possible end use requirements. These results are consistent with the information provided graphically in **Figures 18** and **19**. Actual upper service temperatures may differ from the results in the table depending on such factors as aging under load, chemical exposure, support from substrate, etc. These upper service temperatures should be used as guidelines. End use performance testing should be done to verify the acceptability of *Tefzel®* for each specific application.

Table 6a
Estimated Upper Service Temperatures (°C), No Load Thermal Aging
End-of-Life Criterion Based on Elongation

End-of-Life Criterion		Exposure Time, hr					
Actual Elongation	Elongation Retained, %	1000	3000	10k	20k*	50k*	100k*
135%	50	210	195	172	159	143	132
50%	18	**	211	188	175	158	147
25%	9	**	**	196	182	165	153

*These estimates were extrapolated from 10,000 hour aging results.
**Estimates are not available for these exposure regions.

Table 6b
Estimated Upper Service Temperatures (°C), No Load Thermal Aging
End-of-Life Criterion Based on Tensile Strength

End-of-Life Criterion		Exposure Time, hr			
Actual Tensile Strength	Tensile Strength Retained, %	10k	20k*	50k*	100k*
3,750 psi	50	190	176	159	147
2,000 psi	27	204	190	172	158

*These estimates were extrapolated from 10,000 hour aging results.

One conventional definition of upper service temperature is the lowest temperature at which one of the key physical properties is diminished by one half after 20,000 hours. Using **Tables 6a** and **6b**, *Tefzel*® 200 has a 20,000 hour half-life temperature of approximately 159°C (318°F). (For *Tefzel*®, elongation decreases faster than tensile strength, thus the 20,000 hour half life for tensile strength is 176°C [349°F].)

Another definition of upper service temperature is the temperature at which the elongation drops to 50% after 20,000 exposure hours. The expected upper service temperature would be 175°C (347°F) (see **Table 6a**).

Electrical Properties

Tefzel® exhibits high resistivity and low losses. *Tefzel*® has a dielectric constant of 2.5–2.6 at frequencies below 10 MHz. At higher frequencies, the value decreases to approximately 2.3 at 10 GHz. The dissipation factor is below 0.001 at low frequencies but gradually increases to a peak at about 0.023 at approximately 100 MHz, after which it decreases to below 0.01 at 10 GHz. The changes are shown graphically in **Figures 13** and **14**. The effects of both frequency and temperature on both dielectric constant and dissipation for *Tefzel*® 200 are shown in **Figures 15** and **16**. Values for *Tefzel*® 280 and *Tefzel*® 210 are similar.

The dielectric breakdown strength at various thickness levels is shown in **Figure 17**.

The addition of glass reinforcement raises the losses of *Tefzel*® HT-2004 as would be expected.

As with other materials, exposure to radiation raises the losses.

Figure 13. DuPont™ *Tefzel*® 200 Dielectric Constant—Room Temperature

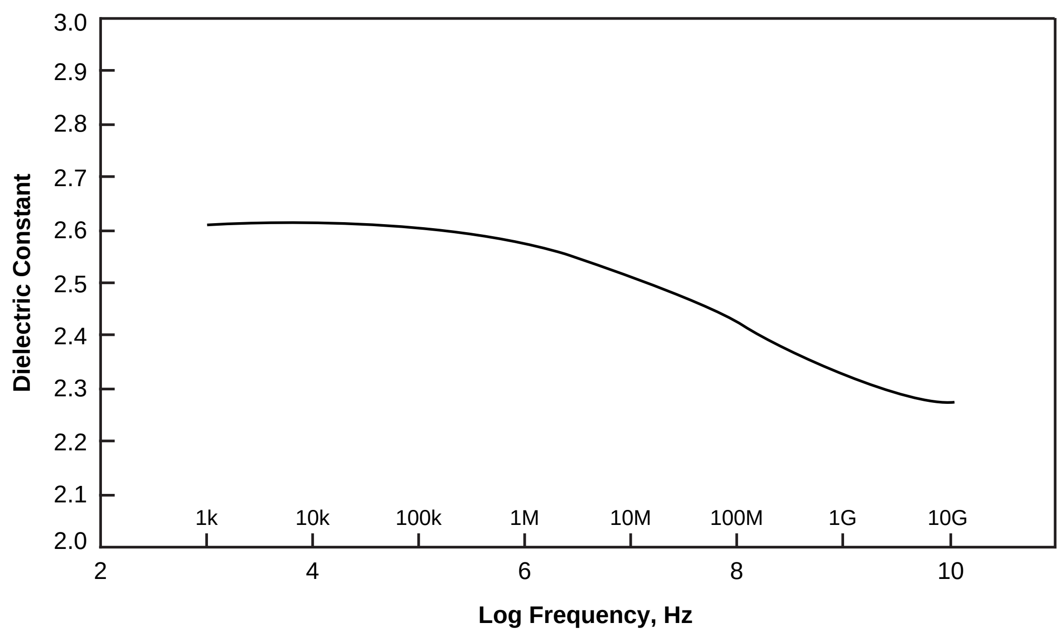


Figure 14. DuPont™ *Tefzel*® 200—Dissipation Factor—Room Temperature

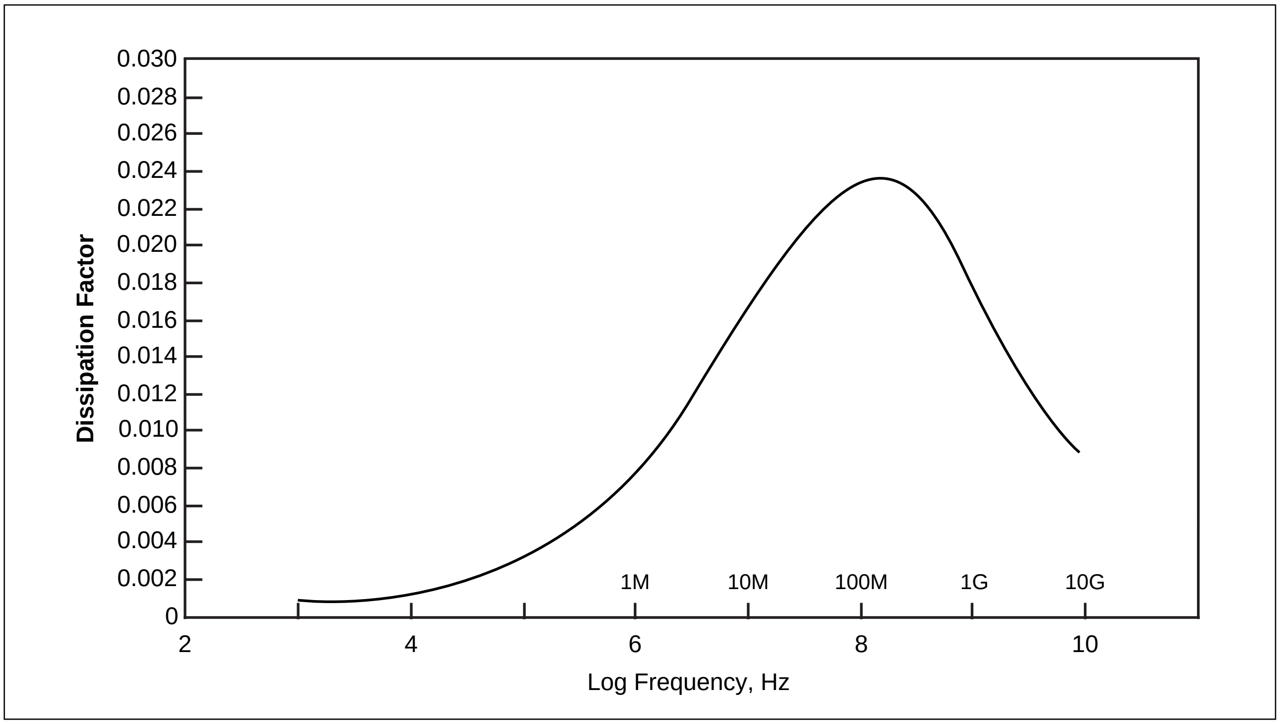


Figure 15. DuPont™ *Tefzel*® 200—Dielectric Constant—Elevated Temperature

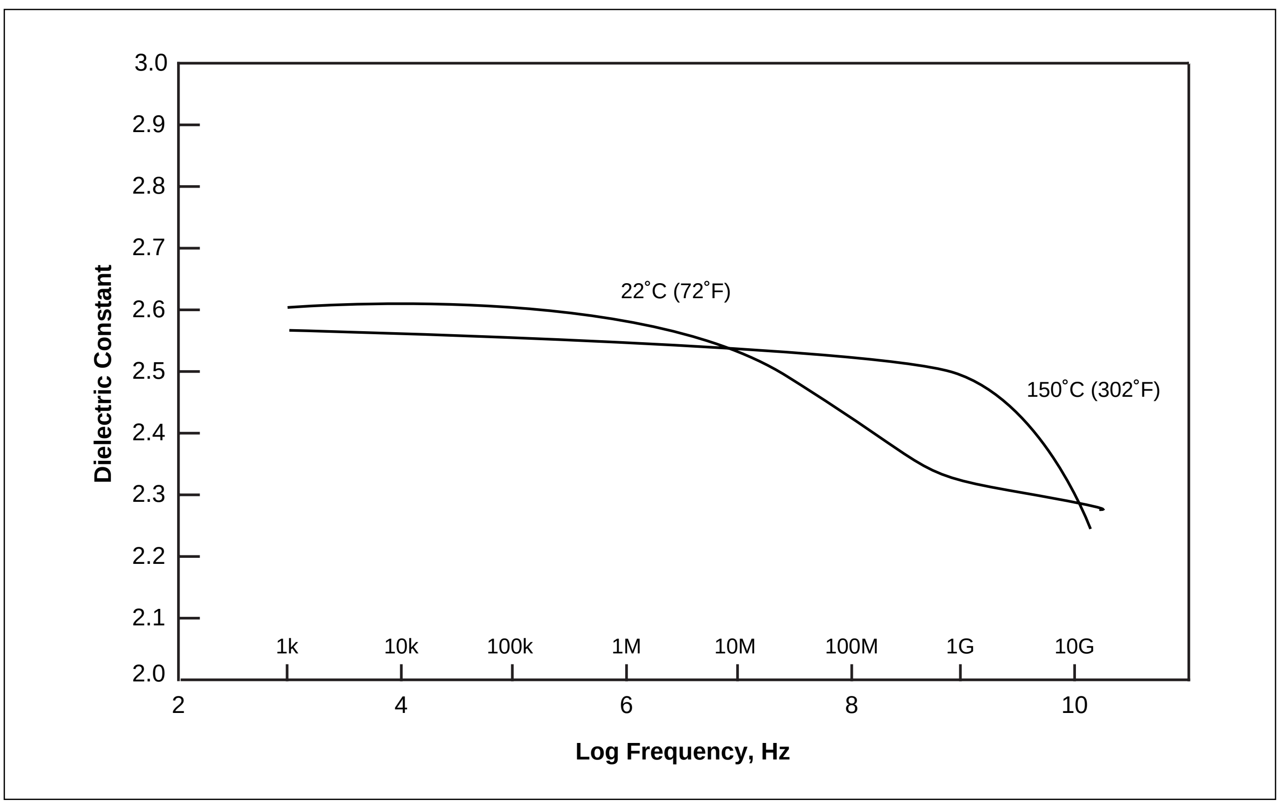


Figure 16. DuPont™ *Tefzel*® 200—Dissipation Factor—Elevated Temperature

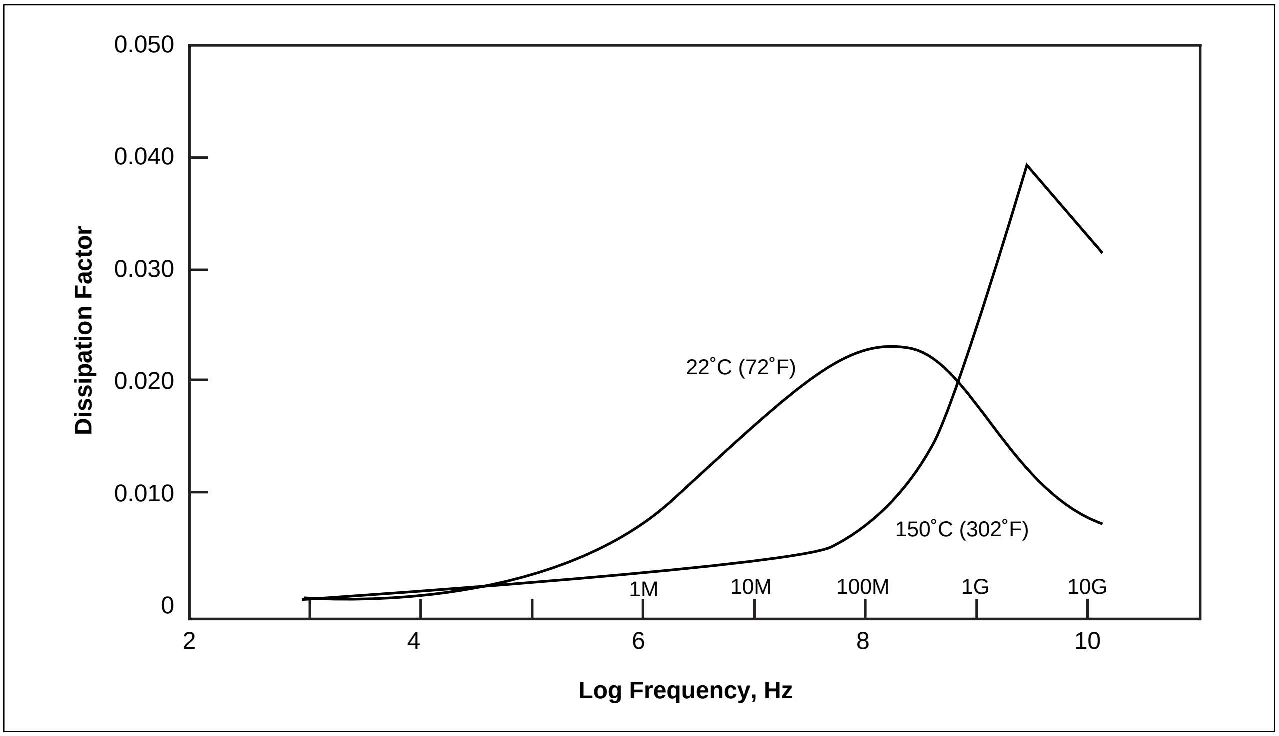
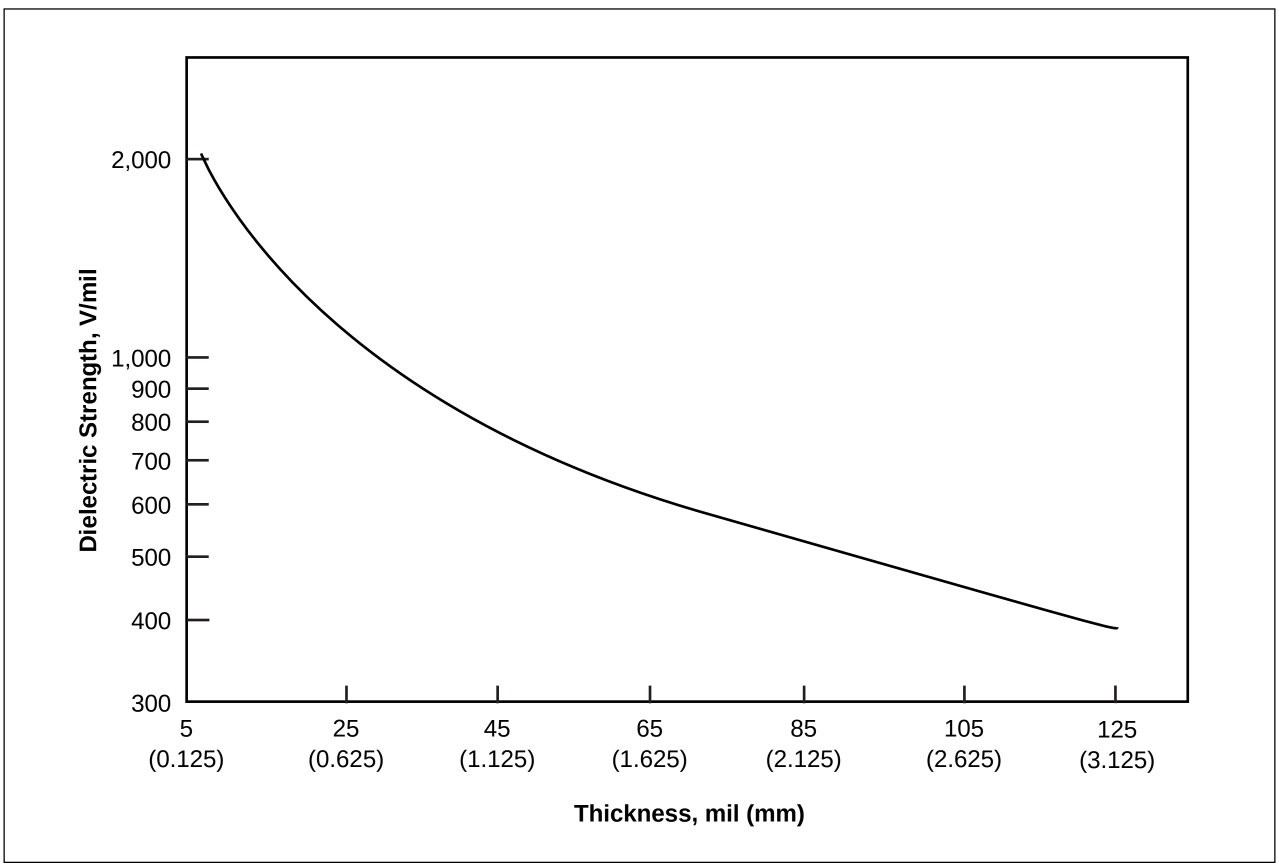


Figure 17. Dielectric Breakdown Strength at Various Thickness Levels for DuPont™ *Tefzel*® 200 and 280



Environmental Effects

Environmental behavior refers to the reaction of *Tefzel*® when exposed to chemicals, sunlight, moisture, radiation (gamma or electron beam), or the effects of temperature aging.

Chemical Resistance

Tefzel® has outstanding resistance to attack by chemicals and solvents that often cause rapid deterioration of other plastic materials. It is surpassed only by *Teflon*® in resistance to chemicals. *Tefzel*® is inert to many strong mineral acids, inorganic bases, halogens and metal salt solutions. Carboxylic acids, anhydrides, aromatic and aliphatic hydrocarbons, alcohols, aldehydes, ketones, ethers, esters, chlorocarbons, and classic polymer solvents have little effect on *Tefzel*®. Under highly stressed conditions, some very low surface tension solvents tend to reduce the stress-crack resistance of the lower molecular weight products. Very strong oxidizing acids such as nitric, organic bases such as amines, and sulfonic acids at high concentrations and near their boiling points will affect *Tefzel*® to varying degrees.

Tefzel® HT-2004 shows chemical resistance similar to the base fluoropolymer, except in cases where reinforcing glass may be attacked by the chemical media. There is evidence that strong oxidizing agents, particularly at high temperatures, will attack the bond between the glass and polymer causing a reduction in reinforcement.

Table 7 presents data on the effect of various chemicals on the tensile properties of *Tefzel*® and the weight gain, if any, during exposure.

Hydrolytic Stability and Water Absorption

Hydrolytic stability is indicated by lack of deterioration in physical properties after long periods of exposure to boiling water.

Using room temperature tensile strength and elongation as control properties, *Tefzel*® 200 is essentially unaffected after 3,000 hours exposure to boiling water. *Tefzel*® 280 behaves similarly.

Tefzel® HT-2004 shows a decrease in tensile strength of 25–35% after 3,000 hours exposure to boiling water. The composition loses its reinforcement characteristics but the actual polymer does not appear to be affected. Data are shown in **Table 8**.

Water absorption for unfilled *Tefzel*® is less than 0.03% by weight as determined by ASTM D570.

Weather Resistance

Tefzel® has excellent resistance to outdoor weathering. Long-term outdoor exposures show little detrimental effects.

Effects of Radiation

Tefzel® is much more resistant to electron beam and gamma radiation than is *Teflon*® fluoropolymer resin. Tests have shown that both elevated temperatures and the presence of oxygen have a deleterious effect on physical properties when *Tefzel*® is exposed to gamma radiation. The effect on physical properties is significantly decreased in an inert atmosphere, such as nitrogen.

Tefzel® appears to be degraded much less with electron beam radiation than with gamma radiation at equivalent levels of total exposure. The difference is probably due to the much higher dosage rate under electron beam conditions. The higher dosage rate apparently allows crosslinking reactions to predominate while the much slower rate under gamma radiation apparently allows competing oxidation and degradation reactions to predominate. Controlled exposure to low levels of electron beam radiation, especially in inert atmospheres, appears to result in a low level of cross-linking with an inherent improvement in some properties. However, exposure beyond the low level controlled conditions results in detrimental effects on physical properties. As with gamma radiation, oxidation reactions are inhibited under inert atmospheres.

Vacuum Outgassing

Under vacuum conditions, *Tefzel*® 200 and *Tefzel*® 280 give off little gas at recommended maximum use temperatures. Values for *Tefzel*® are comparable to *Teflon*®. Data are given in **Table 9**.

Table 7
Actual Laboratory Tests on
Chemical Compatibility of DuPont™ *Tefzel*® with Representative Chemicals

Chemical	Boiling Point °C	Boiling Point °F	Test Temperature °C	Test Temperature °F	Days	Retained Properties, % Tensile Strength	Retained Properties, % Elongation	Retained Properties, % Weight Gain
Acid/Anhydrides								
Acetic Acid (Glacial)	118	244	118	244	7	82	80	3.4
Acetic Anhydride	139	282	139	282	7	100	100	0
Trichloroacetic Acid	196	384	100	212	7	90	70	0
Aliphatic Hydrocarbons								
Mineral Oil	—	—	180	356	7	90	60	0
Naphtha	—	—	100	212	7	100	100	0.5
Aromatic Hydrocarbons								
Benzene	80	176	80	176	7	100	100	0
Toluene	110	230	110	230	7	—	—	—
Functional Aromatics								
O-Cresol	191	376	180	356	7	100	100	0
Amines								
Aniline	185	365	120	248	7	81	99	2.7
Aniline	185	365	120	248	30	93	82	—
Aniline	185	365	180	356	7	95	90	—
N-Methyl Aniline	195	383	120	248	7	85	95	—
N-Methyl Aniline	195	383	120	248	30	100	100	—
N, N-Dimethyl Aniline	190	374	120	248	7	82	97	—
n-Butylamine	78	172	78	172	7	71	73	4.4
Di-n-Butylamine	159	318	120	248	7	81	96	—
Di-n-Butylamine	159	318	120	248	30	100	100	—
Di-n-Butylamine	159	318	160	320	7	55	75	—
Tri-n-Butylamine	216	421	120	248	7	81	80	—
Tri-n-Butylamine	216	421	120	248	30	100	100	—
Pyridine	116	240	116	240	7	100	100	1.5
Chlorinated Solvents								
Carbon Tetrachloride	78	172	78	172	7	90	80	4.5
Chloroform	62	144	61	142	7	85	100	4.0
Dichloroethylene	77	170	32	90	7	95	100	2.8
Methylene Chloride	40	104	40	104	7	85	85	0
Freon, 113	46	115	46	115	7	100	100	0.8
Ethers								
Tetrahydrofuran	66	151	66	151	7	86	93	3.5
Aldehyde/Ketones								
Acetone	56	132	56	132	7	80	83	4.1
Acetophenone	201	394	180	356	7	80	80	1.5
Cyclohexanone	156	312	156	312	7	90	85	0
Methyl Ethyl Ketone	80	176	80	176	7	100	100	0
Esters								
n-Butyl Acetate	127	260	127	260	7	80	60	0
Ethyl Acetate	77	170	77	170	7	85	60	0
Polymer Solvents								
Dimethylformamide	154	309	90	194	7	100	100	1.5
Dimethylformamide	154	309	120	248	7	76	92	5.5
Dimethylsulfoxide	189	373	90	194	7	95	90	1.5
Other Organics								
Benzyl Alcohol	205	401	120	248	7	97	90	—
Benzoyl Chloride	197	387	120	248	7	94	95	—
Benzoyl Chloride	197	387	120	248	30	100	100	—
Decalin	190	374	120	248	7	89	95	—
Phthaloyl Chloride	276	529	120	248	30	100	100	—

(continued)

Table 7
Actual Laboratory Tests on
Chemical Compatibility of DuPont™ *Tefzel*® with Representative Chemicals *(continued)*

Chemical	Boiling Point °C	Boiling Point °F	Test Temperature °C	Test Temperature °F	Days	Retained Properties, % Tensile Strength	Retained Properties, % Elongation	Retained Properties, % Weight Gain
Acids								
Hydrochloric (Conc)	106	223	23	73	7	100	90	0
Hydrochloric (Conc)	106	223	106	223	7	96	100	0.1
Hydrobromic (Conc)	125	257	125	257	7	100	100	—
Hydrofluoric (Conc)	—	—	23	73	7	97	95	0.1
Sulfuric (Conc)	—	—	100	212	7	100	100	0
Sulfuric (Conc)	—	—	120	248	7	98	95	0
Sulfuric (Conc)	—	—	150	302	*	98	90	0
Aqua Regia	—	—	90	194	*	93	89	0.2
Nitric—25%	100	212	100	212	14	100	100	—
Nitric—50%	105	221	105	221	14	87	81	—
Nitric—70% (Conc)	120	248	23	73	105	100	100	0.5
Nitric—70% (Conc)	120	248	60	140	53	100	100	—
Nitric—70% (Conc)	120	248	120	248	2	72	91	—
Nitric—70% (Conc)	120	248	120	248	3	58	5	—
Nitric—70% (Conc)	120	248	120	248	7	0	0	—
Chromic	125	257	125	257	7	66	25	—
Phosphoric (Conc)	—	—	100	212	7	—	—	—
Phosphoric (Conc)	—	—	120	248	7	94	93	0
Halogens								
Bromine (Anhy)	59	138	23	73	7	90	90	1.2
Bromine (Anhy)	59	138	57	135	7	99	100	—
Bromine (Anhy)	59	138	57	135	30	94	93	3.4
Chlorine (Anhy)	—	—	120	248	7	85	84	7
Bases								
Ammonium Hydroxide	—	—	66	150	7	97	97	0
Potassium Hydroxide (20%)	—	—	100	212	7	100	100	0
Sodium Hydroxide (50%)	—	—	120	248	7	94	80	0.2
Peroxides								
Hydrogen Peroxide (30%)	—	—	23	73	7	99	98	0
Salt-Metal Etchants								
Ferric Chloride (25%)	104	220	100	212	7	95	95	0
Zinc Chloride (25%)	104	220	100	212	7	100	100	0
Other Inorganics								
Sulfuryl Chloride	68	115	68	155	7	86	100	8
Phosphoric Trichloride	75	167	75	167	7	100	98	—
Phosphoric Oxychloride	104	220	104	220	7	100	100	—
Silicon Tetrachloride	60	140	60	140	7	100	100	—
Water	100	212	100	212	7	100	100	0
Miscellaneous								
Skydrol	—	—	149	300	7	100	95	3.0
Aerosafe	—	—	149	300	7	92	93	3.9
A-20 Stripper Solution	—	—	140	284	7	90	90	—

*Exposed for 6 hours.

NOTES: Change in properties -15% is considered insignificant. Samples were 10–15 mil microtensile bars. TS/E and wt. gain determined within 24 hours after removal from exposure media.

Table 8
Resistance to Boiling Water—DuPont™ *Tefzel*® 200 and HT-2004

Product	Tensile Strength psi	Tensile Strength MPa	Elongation, %
Tefzel® 200 (no exposure)	5,800	40	145
3,000 hours boiling water	5,790	40	135
Tefzel® HT-2004 (no exposure)	11,890	82	7
1,000 hours exposure*	8,960	60	5
2,000 hours exposure*	8,360	57.6	5
3,000 hours exposure*	8,110	55.8	5

*Measured at 23°C (73°F) after immersion in boiling water

Table 9
Vacuum Outgassing—
DuPont™ *Tefzel*® 200 and *Tefzel*® 280*

Weight Loss, %	
Maximum	0.12
Generally accepted maximum 1%	
Minimum	0.04
Average	0.07
Volatile Condensable Material Weight (VCMW), %	
Maximum	0.02
Minimum	0.00
Average	0.01

*Tests consist of exposing 30 mil thick specimens for 24 hours in a hard vacuum at 149°C (300°F) and measuring weight loss and the volatile gases that are collected in liquid air traps.

Permeability

Tests measured on 4 mil thick film per ASTM D1434 at 25°C (77°F) show the following permeabilities:

Material	Permeability, $cm^3/100\ in^2 \cdot 24\ h \cdot atm/mil$*
Carbon Dioxide	250
Nitrogen	30
Oxygen	100

*Multiply by 15.5 to obtain $cm^3/m^2 \cdot day \cdot atm$

Water vapor transmission by ASTM E96 is 1.65 $g/100\ in^2 \cdot 24\ h/mil$.

Flame Resistance and Smoke

Tefzel® is rated UL94 V-0 for unpigmented resins down to 0.062 in thick. Its limiting oxygen index (LOI) is 30 by ASTM D2863, which means that an atmosphere containing at least 30% oxygen is required to maintain combustion in a downward burning flame. By ASTM D635, *Tefzel*® has an average time of burning (ATB) of less than 5 seconds and an average length of burn (ALB) of 10 mm (0.39 in).

Effects of Heat Aging

Most polymeric materials are affected to some degree when exposed to elevated temperatures for long periods of time.

Figure 19 shows how room temperature tensile strength is affected by exposure time and temperatures. These data were obtained on specimens exposed to no mechanical stress during aging and so are *directly* pertinent only to a device, e.g., a wire, which is exposed to temperature with little or no load, and then is mechanically stressed at room temperature.

To demonstrate the use of **Figure 19**, determine what exposure at 135°C (275°F) will reduce tensile strength to 3,000 psi. From these data, the answer is over 30 years. At 180°C (356°F), the time is just over 2 years. At the *rated* temperature of 150°C (302°F), the time is over 10 years.

Figure 18 is a similar graph for room-temperature elongation and is used in the same fashion as the tensile data in **Figure 19**.

Figure 18. Retention of Room Temperature Tensile Elongation After Aging—DuPont™ *Tefzel*® 200

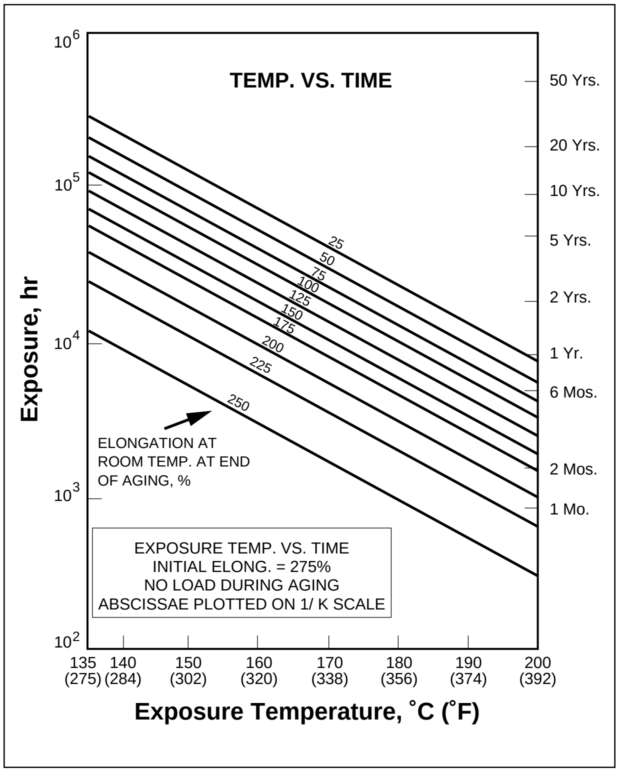


Figure 19. Retention of Room Temperature Tensile Strength After Aging—DuPont™ *Tefzel*® 200

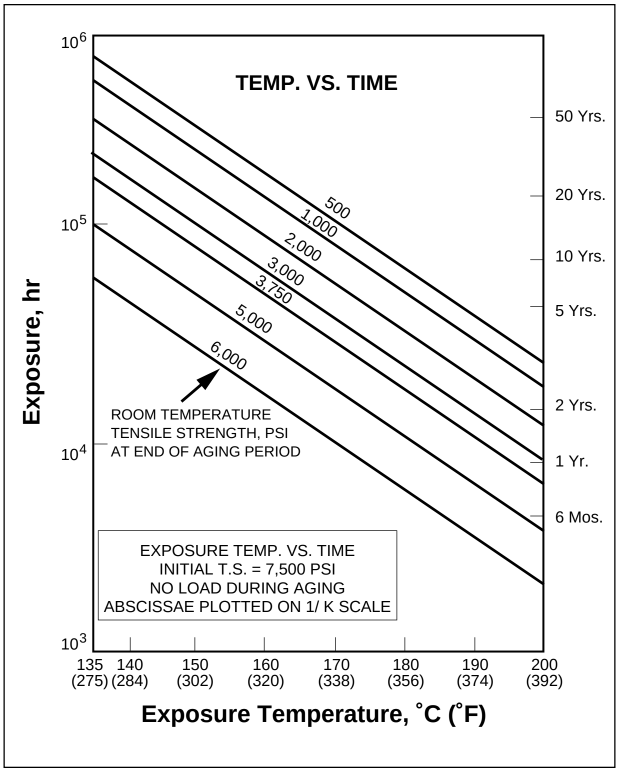


Figure 20 shows the effect of heat aging of *Tefzel*® HT-2004 on tensile properties aged at 204°C (400°F) and 230°C (392°F) with tensile measurements being made at both room temperature and 150°C (302°F).

The effect of heat aging on the impact strength of *Tefzel*® HT-2004 is shown in **Table 10**.

Short-term exposure at 150°C (302°F) causes no measurable loss of impact strength while such exposure at 180°C (356°F) does cause a small decrease.

Figure 20. Effect of Heating of DuPont™ *Tefzel*® HT-2004 (All values of elongation between 5 and 10% regardless of test temperature) (no load during aging)

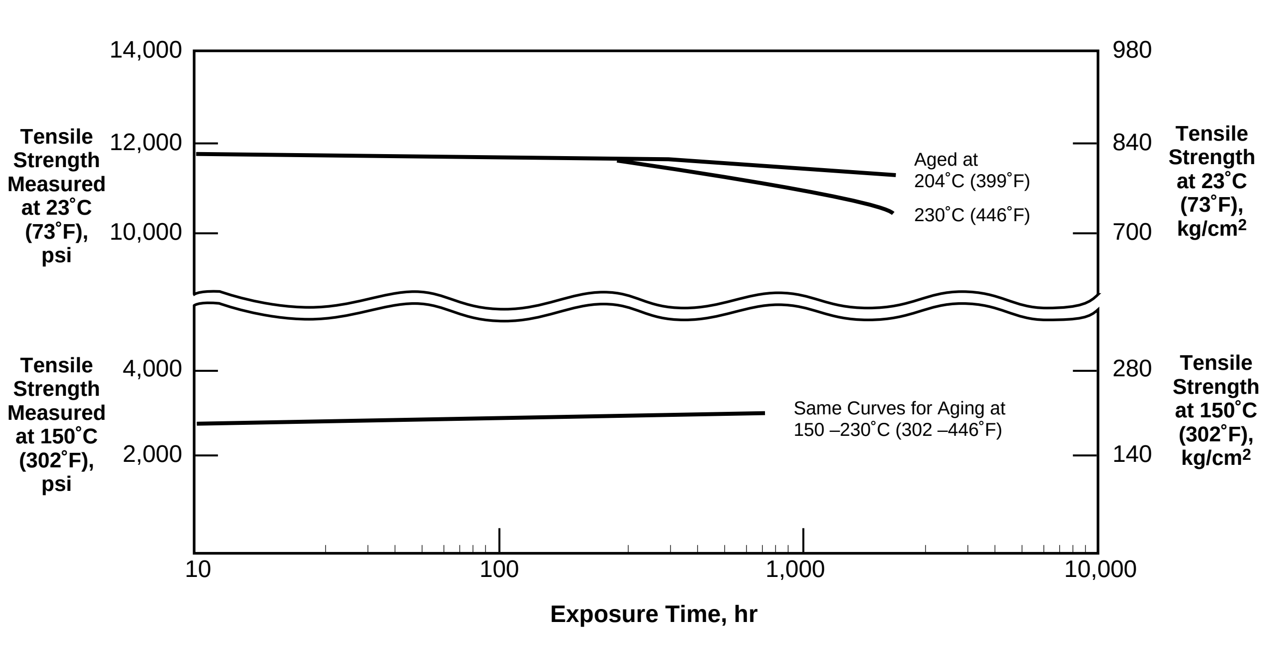


Table 10
Effect of Temperature Aging on Izod Impact Strength, DuPont™ *Tefzel*® HT-2004

Temperature			Izod Impact Strength	
°C	°F	Aging	J/m	ft·lb/in
23	73	as molded	491	9.1
23	73	168 hours at 150°C (302°F)	491	9.1
23	73	168 hours at 180°C (356°F)	416	7.7

Loss of Weight with Aging

The weight loss of *Tefzel*® below the melting point is from 0.1 to 0.3% most of which is moisture. The weight loss above 300°C (572°F) is shown in **Table 11**.

Table 11
Initial Weight Loss of DuPont™ *Tefzel*® Resins Above 300°C (572°F)

Temperature		Tefzel 200
°C	°F	wt loss, %/hr
300	572	0.05
330	626	0.26
350	662	0.86
370	698	1.60

Optical Properties

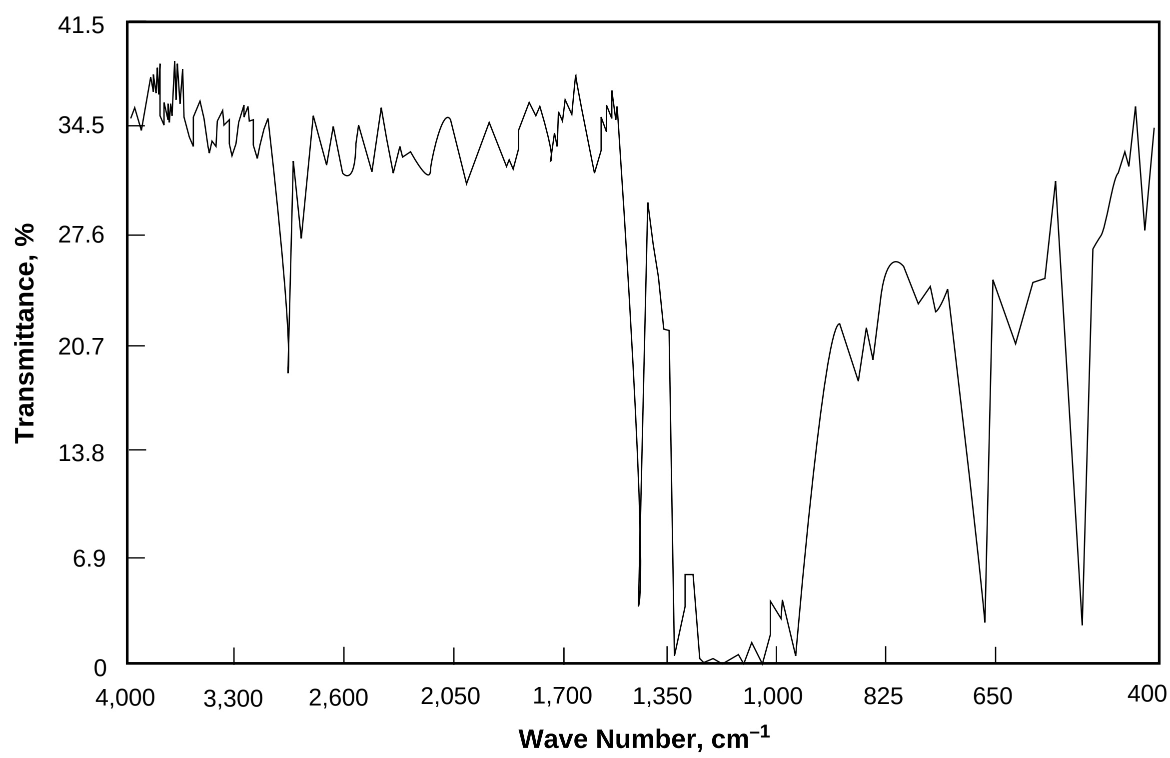
Data on percent transmittance vs. wavelength is given in **Table 12**. **Figure 21** shows a typical infrared scan of *Tefzel*® films.

Table 12
Transmittance vs. Wavelength Data Normalized to 0.025 mm (1.0 mil) Films (Beer's Law)

Wavelength, nm	*Tefzel*® Film Transmittance, %*
Ultraviolet Range	
200	91.5
250	92
300	92
350	93
400	94
Visible Range	
500	94
600	94
700	95
800	95

* Hitachi Model V-3210 spectrometer with 60 mm diameter, 151-0030 integrating sphere, scan speed 60 mm/min

Figure 21. Infrared Scan of DuPont™ *Tefzel*®, 0.025 mm (1 mil)



Fabrication Techniques

Tefzel®, as a thermoplastic polymer, can be processed by most techniques applicable to this type of resin. Included are:

- Injection molding
- Compression molding
- Rotational molding
- Extrusion

Tefzel® can also be formed, machined, colored, and printed upon using techniques described in appropriate processing bulletins.

Assembly Techniques

The success of many applications depends on the ability of *Tefzel*® to be economically assembled using one or more of a variety of assembly techniques. Some of these techniques suitable for *Tefzel*® compositions are described below. More information or assistance in evaluating these for use in specific projects involving *Tefzel*® is available through your DuPont representative.

Screw Assemblies

Self-tapping screws are used for joining parts of *Tefzel*®. Either of two types (the thread cutting, which taps a mating thread as the screw is driven, or the thread forming that mechanically displaces material as the screw is driven) can reduce assembly cost.

A rule of thumb is that the boss diameter should be about 2-1/2 times the screw diameter for maximum holding power. Lubricants should be avoided for maximum stripping torque.

Threaded inserts are also used. They can be molded in place, pressed in, or driven in ultrasonically.

Snap-Fit

The advantage of snap-fit joints is that the strength of the joint does not diminish with time because of creep. The lower ductility of *Tefzel*® HT-2004 suggests that other assembly methods be used for this product, although snap-fits are possible at low strains.

Two types of snap-fits are:

1. A cylindrical snap-fit for joining a steel shaft and a hub of *Tefzel*®.
2. A cantilevered lug snap-fit for inserting a *Tefzel*® part into another part.

In a cylindrical snap-fit joint (**Figure 22**), the maximum strain at the inside of the hub is the ratio of interface (I) to diameter (D_s) (x 100 for percent). A maximum strain of about 5% is suggested.

$$\text{Max. Strain} = I/D_s \times 100 - 5\%$$

For the cantilevered lug snap-fit joint, the maximum strain is expressed by the equation:

$$\text{Max. Strain} = 3Yh/2L^2 \times 100 \leq 5\%$$

Again, a 5% maximum strain is suggested.

Press Fit

Press fit joints are simple and inexpensive, however, the holding power is reduced with time. Creep and stress relaxation reduce the effective interference as do temperature excursions particularly when materials with different thermal expansions are joined.

With *Tefzel*® joined to *Tefzel*®, the press fit joint may be designed with an interference resulting in strains of 6–7%.

$$\text{Strain} = \frac{\text{Interference (on diameter)} \times 100}{\text{Shaft Diameter}}$$

Shaft Diameter

If a part of *Tefzel®* and one of metal are to be joined, lower strain levels may be used.

Assembly can often be made easier by inserting a cooled part into a heated hub.

Cold or Hot Heading

Rivets or studs can be used in forming permanent mechanical joints. The heading is accomplished with special tools and preferably with the rivet at elevated temperatures.

Formed heads tend to recover part of their original shape if exposed to elevated temperatures, so joints can become loose. Forming at elevated temperatures tends to reduce recovery.

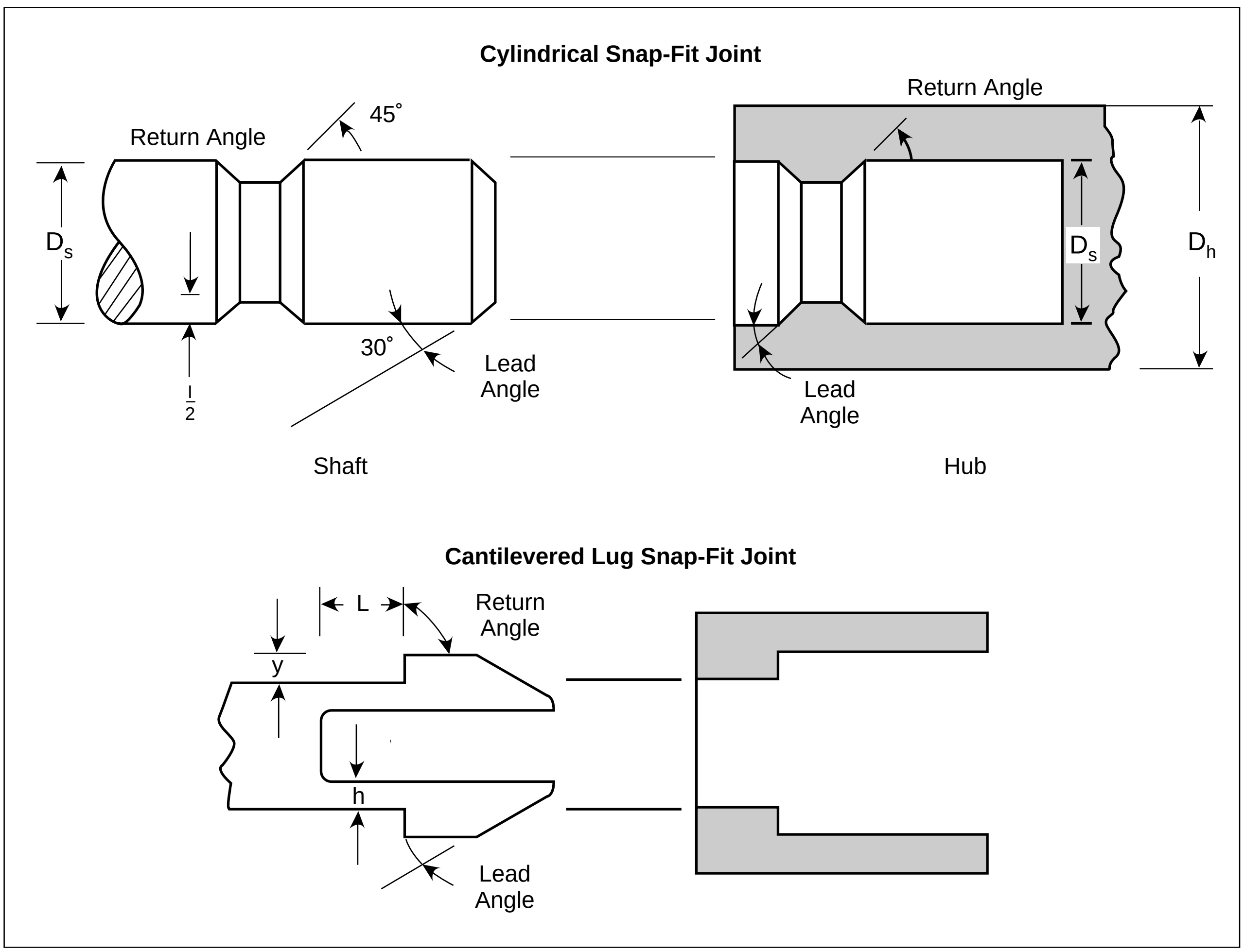
Spin Welding

Spin welding is an efficient assembly technique for joining circular surfaces of similar materials. The matching surfaces are rotated at high speed relative to each other (one surface is fixed) and then brought into contact. Frictional heat melts the interface and when motion is stopped, the weld is allowed to solidify under pressure.

Ultrasonic Welding

The ultrasonic welding of *Tefzel®* has been demonstrated with weld strengths up to 80% of the strength of the base resin. The success of developments involving this technique depends upon joint design and the experimentally-determined welding parameters of contact time and pressure. Typical welding conditions are 25 psi contact pressure and one- or two-second cycle time. Both employ a small initial contact area to concentrate and direct the high-frequency vibrational energy.

Figure 22. Snap-Fit Joints



Potting

Potting of wires insulated with *Tefzel*® has been accomplished with the aid of a coating of a colloidal silica dispersion using various polysulfide potting compounds. Such pretreatment tends to increase the pull-out strengths by 25 to 50%.

Adhesive Bonding

Because of the outstanding chemical resistance of *Tefzel*®, surface treatment is required to allow adhesive bonding. Chemical etch, corona, or flame treatments can be used to make surfaces of *Tefzel*® more receptive to adhesives. Polyester and epoxy compounds are suitable adhesives when surfaces are properly prepared.

Melt Bonding

Tefzel® responds well to melt bonding. It has been bonded to untreated aluminum, steel, and copper with peel strengths in excess of 20 lb/in. It can also be melt bonded to itself using such techniques as hot plate welding.

The bond is achieved by heating the materials to 270°–275°C (520°–530°F), then pressing the parts together during cooling.

Safety Precautions

WARNING!

VAPORS CAN BE LIBERATED WHICH MAY BE HAZARDOUS IF INHALED.

Before using Tefzel, read the detailed information in the “Guide to the Safe Handling of Fluoropolymer Resins,” latest edition, published by the Fluoropolymers Division of The Society of the Plastics Industry—available from DuPont.

Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing, or from smoking tobacco or cigarettes contaminated with Tefzel, may cause flu-like symptoms (chills, fever, sore throat) that may not occur until several hours after exposure and that typically pass within about 24 hours. Vapors and fumes liberated during hot processing should be exhausted completely from the work area; contamination of tobacco with polymers should be avoided.

Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.

Typical Applications

No other plastic resin comes as close to the fluoropolymers in chemical and electrical properties while providing a high level of mechanical ruggedness and easy, economical processing. *Tefzel*® allows a range of opportunities for design engineers to achieve better product performance in many application areas.

Bearings

Glass-reinforced *Tefzel*® is suited for load bearing applications in abusive environments. A low wear factor (one-tenth that of reinforced nylon) and good creep resistance make it an excellent bearing material.

Fasteners

Cable and hydraulic line clamps, cable straps, and other fasteners molded of *Tefzel*® perform in high temperature, corrosive environments. Nuclear applications are possible because of the radiation resistance of *Tefzel*®. Moisture absorption is low, providing uniformity of mechanical properties regardless of humidity. High impact strength and UV resistance are additional advantages.

Outstanding electrical properties, solvent resistance, an SE-O flammability rating,* and excellent high temperature aging characteristics make *Tefzel*® an ideal material for high performance electrical components. Coil forms, connectors, encapsulated parts, sockets, and insulators are typical applications.

Valve Linings

Tefzel® has replaced other polymers and glass as a valve lining. The outstanding resistance of *Tefzel*® to acids, bases, and solvents over a broad temperature range, combined with abrasion resistance and ease of processing, results in a durable and economical valve.

Film Form Available

Film of *Tefzel*® can be heat sealed, thermoformed, welded, heat laminated, and coated to make pressure-sensitive tapes, flexible printed circuits, liquid pouches, and other constructions where strength, thermal resistance, and electrical integrity are required.

Tubing

Heat-shrinkable, plain, and corrugated tubing is available in a wide range of thicknesses and diameters. It is being used at high temperatures as electrical insulation and in service with strong chemicals.

Heat-shrinkable tubing conforms to electrical terminations, hose connections, and other components to insulate, guard against abrasion, and prevent corrosion.

Wire and Cable

Tough insulation of *Tefzel*® is being used on conductors ranging from AWG #30 for wrapped computer terminations to 535 MCM for heavy power circuits. *Tefzel*® is performing well on steel mill cables, airframe wire, down-hole oil well logging cable, rapid transit car and locomotive control wire, and other rugged service wire and cable. It is receiving special consideration for use in nuclear power plants and other areas where exposure to radiation may be encountered.

Biomedical/Labware

High impact strength, chemical resistance, resistance to high heat sterilization, and ease of processing are properties needed for biomedical and labware applications. Oxygen respirator components, blood analyzer valves, evaporating dishes, and centrifuge tubes are examples.

Pump Components

Chemical resistance, dimensional stability, and structural strength make *Tefzel*® a candidate for pump impellers, vanes, gears, and bodies.

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* Numerical flame spread ratings are not intended to reflect hazards presented by this or any other material under actual fire conditions.

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CAUTION: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.

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