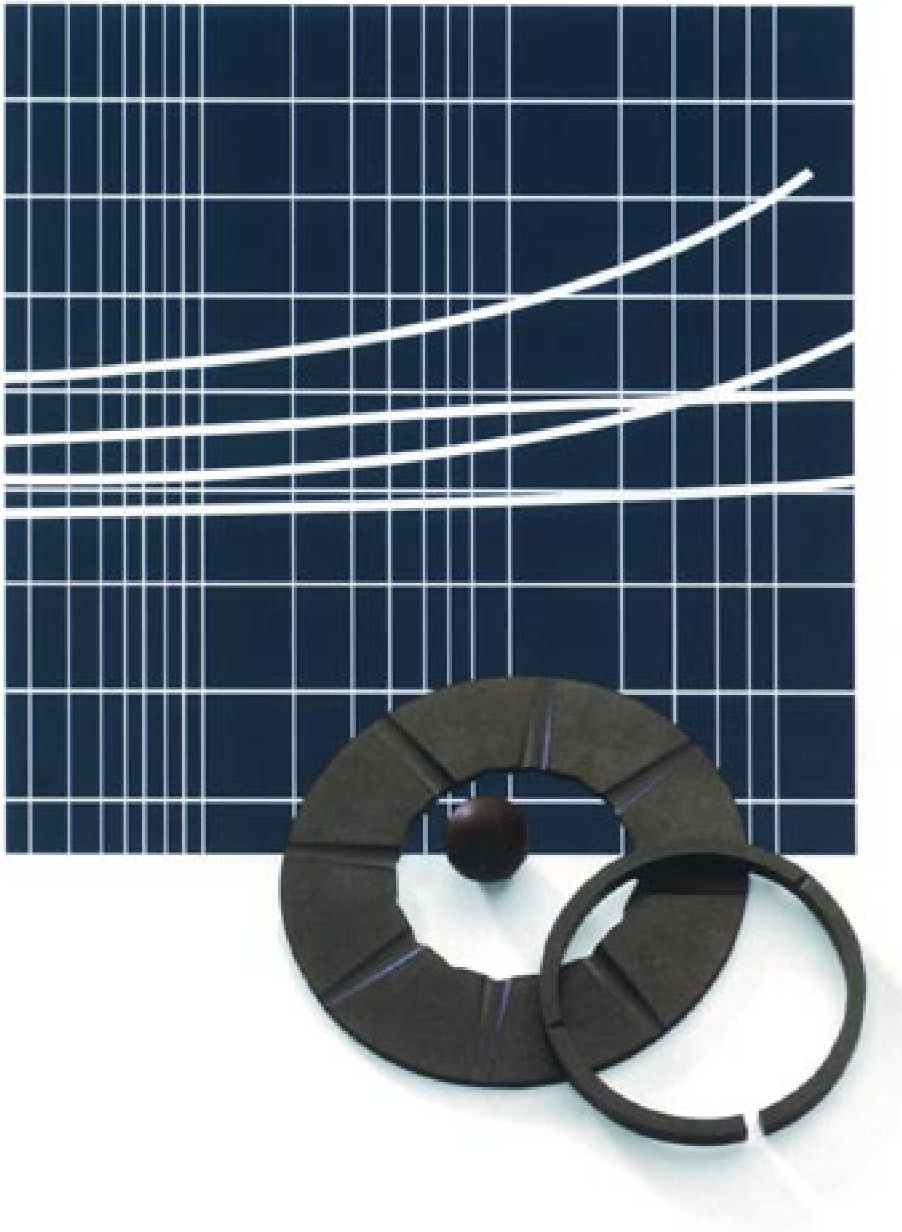
Properties of DuPont VESPEL® Parts



Start with DuPont

VESPEL® Territory . . . Performance Plus

Introduction

If you need to insure the dependable performance of parts critical to the successful operation of your design, you may be in **Vespel** Territory.

If you need to reduce warranty costs caused by the premature failure of critical parts in an existing product, you may be in **Vespel** Territory.

If you need any combination of

- Low wear and friction at high pressures and velocities,
- Outstanding creep resistance,
- Lubricated or unlubricated performance,
- Strength and impact resistance, or
- Continuous operation at 500°F with excursions to 900°F

*You're in **Vespel** Territory.*

Vespel parts, manufactured by DuPont to your design from high performance polyimide resin, provide a unique combination of the physical properties of plastics, metals and ceramics. **Vespel** parts offer you design flexibility. Often several parts can be combined into one, parts can be designed to simplify product assembly, or parts can be eliminated. As with metals and ceramics, **Vespel** parts can successfully perform in demanding physical environments.

The property data which follows, except where noted, are the result of extensive testing of parts machined from SP polyimide shapes. If your need involves the production of more than 1,000 parts a year you should consider direct-formed **Vespel** parts, normally the most cost-effective way to produce parts for high-volume applications. Contact your local DuPont **Vespel** Marketing Representative before you begin your design. He will be happy to provide information on direct-formed SP parts, to discuss similar applications and to help you obtain **Vespel** materials for testing and prototyping.

Direct-formed SP parts are produced with the pressure applied unidirectionally, resulting in some anisotropy, or directionality, of properties. Directionality is increased with the addition of fillers. The highest strength and elongation and the lowest thermal expansion are found in the direction perpendicular to the pressing direction in most parts. The data presented here for direct-formed parts, except for compressive properties and thermal conductivity, were obtained in the perpendicular direction. The typical properties of machined parts were obtained from samples prepared from isotropic material. The material is formed so that properties are uniform throughout regardless of direction.

Take a moment to explore the boundaries of **Vespel** Territory. See for yourself the superior performance you can obtain by designing with DuPont **Vespel** parts.

Typical Properties

Tables 1 and 2 detail the typical properties of **Vespel** parts made from the various compositions of SP polyimide. Table 1 shows the data in British Units and Table 2 shows the same information in SI Units. Subsequent charts, tables and graphs follow the same practice.

VESPEL® polyimide is available in these five resins compositions to provide a range of property combinations.

RESIN DESIGNATION	DESCRIPTION	CHARACTERISTICS
SP-1	Unfilled base resin	Provides maximum physical properties and best electrical and thermal insulation.
SP-21	*15%, by weight, graphite filler.	Graphite added to provide low wear and friction for bearings, thrust washers, and dynamic seals.
SP-22	*40%, by weight, graphite filler.	Same as SP-21 for wear and friction plus improved dimensional stability. It has the lowest coefficient of thermal expansion.
SP-211	*15%, by weight, graphite and 10% by weight Teflon® fluorocarbon resin fillers.	Has lowest coefficient of friction over wide range of operating conditions. Also, has lowest wear rate up to 300°F.
SP-3	*15%, by weight, molybdenum disulfide.	MoS_2 added to provide lubrication for seals and bearings in vacuum or dry environments.

**Nominal*

TABLE 1
SUMMARY OF TYPICAL PROPERTIES
SP Polyimide Resins (British Units)

Property	Temp. °F	ASTM Method	Units	SP-1		SP-21		SP-22		SP-211		SP-3
				M*	DF*	M	DF	M	DF	M	DF	M
MECHANICAL Tensile Strength, Ultimate	73	D-1708 or E8†	psi	12,500	10,500	9,500	9,000	7,500	6,500	6,500	7,500	8,200
	500			6,000	5,300	5,500	4,400	3,400	3,800	3,500	3,500	—
Elongation, Ultimate	73	D-1708 or E8†	%	7.5	7.5	4.5	5.5	3.0	2.5	3.5	5.5	4.0
	500			6.0	7.0	3.0	5.2	2.0	2.5	3.0	5.3	—
Flexural Strength, Ultimate	73	D-790	psi	16,000	12,000	16,000	12,000	13,000	9,000	10,000	10,000	11,000
	500			9,000	6,500	9,000	7,000	6,500	5,500	5,000	5,000	5,500
Flexural Modulus	73	D-790	10^3 psi	450	360	550	460	700	700	450	400	475
	500			250	210	370	260	400	400	200	200	270
Compressive Stress	73	D-695	psi									
@ 1% Strain				3,600	3,500*	4,200	3,300*	4,600	3,500*	3,000	2,100*	5,000
@ 10% Strain				19,300	16,300*	19,300	15,200*	16,300	13,600*	14,800	11,000*	18,500
@0.1% Offset				7,400	4,800*	6,600	4,900*	6,000	3,700*	5,400	4,000*	—
Compressive Modulus	73	D-695	10^3 psi	350	350*	420	330*	475	385*	300	200*	350
Axial Fatigue Endurance Limit			psi									
@10^3 Cycles	73			8,100		6,700	—	—	—	—	—	—
	500			3,800		3,300	—	—	—	—	—	—
@10^7 Cycles	73			6,100		4,700	—	—	—	—	—	—
	500			2,400		2,400	—	—	—	—	—	—
Flexural Fatigue Endurance Limit			psi									
@10^3 Cycles	73			9,500		9,500	—	—	—	—	—	—
@10^7 Cycles	73			6,500		6,500	—	—	—	—	—	—
Shear Strength	73	D-732	10^3 psi	13.0	—	11.2	—	—	—	—	—	—
Impact Strength, Izod, notched	73	D-256	ft lb/in	0.8	—	0.8	—	—	—	—	—	0.4
Impact Strength, Izod, unnotched	73	D-256	ft lb/in	14	—	6	—	—	—	—	—	2.1
Poisson's Ratio	73			0.41	—	0.41	—	—	—	—	—	—
WEAR and FRICTION Wear Rate††			—	—	—	—	—	—	—	—	—	—
Friction Coefficient** PV-25,000				.29	.29	.24	.24	.20	.20	.12	.12	.25
PV-100,000				—	—	.12	.12	.09	.09	.08	.08	.17
In vacuum				—	—	—	—	—	—	—	—	.03
Static in air				.35	—	.30	—	.27	—	.20	—	—

†† See your local Vespel® marketing representative to review your specific needs.

TABLE 1 (continued)

Property	Temp. °F	ASTM Method	Units	SP-1		SP-21		SP-22		SP-211		SP-3
				M*	DF*	M	DF	M	DF	M	DF	M
THERMAL Coefficient of Linear Expansion	73–572 –80–73	E-228	10^{-6} in/in/°F	30 25	28 —	27 19	23 —	21 —	15 —	30 —	23 —	29 —
Thermal Conductivity	104		BTU in / hr ft² °F	2.4	2.0*	6.0	3.2*	12.0	6.2*	5.3	2.9*	3.2
Specific Heat			BTU/lb °F	0.27	—	—	—	—	—	—	—	—
Deformation under 2000 psi load	122	D-621	%	0.14	0.20	0.10	0.17	0.08	0.14	0.13	0.29	0.12
Deflection Temperature @ 264 psi		D-648	°F	~680	—	~680	—	—	—	—	—	—
ELECTRICAL Dielectric Constant	73	D-150										
@ 10^2 Hz				3.62	—	13.53	—	—	—	—	—	—
@ 10^4 Hz				3.64	—	13.28	—	—	—	—	—	—
@ 10^6 Hz				3.55	—	13.41	—	—	—	—	—	—
Dissipation Factor	73	D-150										
@ 10^2 Hz				.0018	—	.0053	—	—	—	—	—	—
@ 10^4 Hz				.0036	—	.0067	—	—	—	—	—	—
@ 10^6 Hz				.0034	—	.0106	—	—	—	—	—	—
Dielectric Strength, Short time 80 mils thick	73	D-149	Volts/mil	560	—	250	—	—	—	—	—	—
Volume Resistivity	73	D-257	Ω-m	10^{14}–10^{15}	—	10^{12}–10^{13}	—	—	—	—	—	—
Surface Resistivity	73	D-257	Ω	10^{15}–10^{16}	—	—	—	—	—	—	—	—
OTHER PROPERTIES Water Absorption		D-570	%									
24 hrs @ 73°F				.24	—	.19	—	.14	—	.21	—	.23
48 hrs @ 122°F				.72	—	.57	—	.42	—	.49	—	.65
Equilibrium–50% RH				1.0–1.3	1.0–1.3	0.8–1.1	0.8–1.1	—	—	—	—	—
Specific Gravity		D-792		1.43	1.34	1.51	1.42	1.65	1.56	1.55	1.46	1.60
Hardness		D-785	Rockwell "E"	45–60	—	25–45	—	5–25	—	1–20	—	40–55
Limiting Oxygen Index		D-2863	%	53	—	49	—	—	—	—	—	—

† Machined tensile specimens made per D-1708 and direct-formed specimens made per figure 19 of E-8 (standard bar for powdered metallurgy products); specimens tested by D-638.

* Direct-formed (DF) properties marked with asterisk were measured parallel to the forming direction. All other direct-formed properties were measured perpendicular to the forming direction. Machined (M) properties are non-directional.

†† Unlubricated in air (PV-25,000).

** Steady state, unlubricated in air.

TABLE 2
SUMMARY OF TYPICAL PROPERTIES
SP Polyimide Resins (SI Units)

Property	Temp. °K	ASTM Method	Units	SP-1 M	SP-1 DF	SP-21 M	SP-21 DF	SP-22 M	SP-22 DF	SP-211 M	SP-211 DF	SP-3 M
MECHANICAL Tensile Strength, Ultimate	296	D-1708 or E8†	MPa	86.2	72.4	65.5	62.0	51.7	48.3	44.8	51.7	58.5
	533			41.4	36.5	37.9	30.3	23.4	26.2	24.1	24.1	—
Elongation, Ultimate	296	D-1708 or E8†	%	7.5	7.5	4.5	5.5	3.0	2.5	3.5	5.5	4.0
	533			6.0	7.0	3.0	5.2	2.0	2.0	3.0	5.3	—
Flexural Strength, Ultimate	296	D-790	MPa	110.3	82.7	110.3	82.7	89.6	62.1	68.9	68.9	75.8
	533			62.1	44.8	62.0	48.3	44.8	37.9	34.5	34.5	39.9
Flexural Modulus	296	D-790	MPa	3102	2482	3792	3171	4826	4826	3102	2758	3275
	533			1724	1448	2551	1792	2758	2758	1379	1379	1862
Compressive Stress	296	D-695	MPa									
@ 1% Strain				24.8	24.1*	29.0	22.8*	31.7	24.1*	20.7	14.5*	34.5
@ 10% Strain				133.1	112.4*	133.1	104.8*	112.4	93.8*	102.0	75.8*	127.6
@0.1% Offset				51.0	33.1*	45.5	33.8*	41.4	25.5*	37.2	27.6*	
Compressive Modulus	296	D-695	MPa	2413	2413*	2895	2275*	3275	2654*	2068	1379*	2413
Axial Fatigue Endurance Limit												
@10^3 Cycles	296		MPa	55.8		46.2	—	—	—	—	—	—
	533			26.2		22.8	—	—	—	—	—	—
@10^7 Cycles	296			42.1		32.4	—	—	—	—	—	—
	533			16.5		16.5	—	—	—	—	—	—
Flexural Fatigue Endurance Limit												
@10^3 Cycles	296		MPa	65.5		65.5	—	—	—	—	—	—
@10^7 Cycles	296			44.8		44.8	—	—	—	—	—	—
Shear Strength	296	D-732	MPa	89.6		77.2	—	—	—	—	—	—
Impact Strength, Izod, notched	296	D-256	J/m	42.7		42.7						21.3
Impact Strength, Izod, unnotched	296	D-256	J/m	747		320						112
Poisson's Ratio	296			0.41	—	0.41						
WEAR and FRICTION Wear Rate††			—	—	—	—	—	—	—	—	—	—
Friction Coefficient** PV = .875 MPa m/s				.29	.29	.24	.24	.30	.30	.12	.12	.25
PV = 3.5 MPa m/s				—	—	.12	.12	.09	.09	.08	.08	.17
In Vacuum				—	—	—	—	—	—	—	—	.03
Static in air				.35	—	.30	—	.27	—	.20	—	—

†† See your local Vespel® marketing representative to review your specific needs.

TABLE 2 (continued)

Property	Temp. °K	ASTM Method	Units	SP-1		SP-21		SP-22		SP-211		SP-3
				M*	DF*	M	DF	M	DF	M	DF	M
THERMAL												
Coefficient of Linear Expansion	296–573	D-696	µm/m/°K	54	50	49	41	38	27	54	41	52
	211–296			45		34						
Thermal Conductivity	313		W/m °K	.35	.29*	.87	.46*	1.73	.89*	.76	.42*	.47
Specific Heat			J/Kg/°K	1130								
Deformation under 2000 psi load	323	D-621	%	0.14	0.20	0.10	0.17	0.08	0.14	0.13	0.29	0.12
Deflection Temperature @ 264 psi		D-648	°K	~633		~633						
ELECTRICAL												
Dielectric Constant	296	D-150										
@ 10^2 Hz				3.62	—	13.53	—	—	—	—	—	—
@ 10^4 Hz				3.64	—	13.28	—	—	—	—	—	—
@ 10^6 Hz				3.55	—	13.41	—	—	—	—	—	—
Dissipation Factor	296	D-150										
@ 10^2 Hz				.0018	—	.0053	—	—	—	—	—	—
@ 10^4 Hz				.0036	—	.0067	—	—	—	—	—	—
@ 10^6 Hz				.0034	—	.0106	—	—	—	—	—	—
Dielectric Strength, Short time 0.002 m thick		D-149	MV/m	22	—	9.84	—	—	—	—	—	—
Volume Resistivity	296	D-257	Ω-m	10^{14}–10^{15}	—	10^{12}–10^{13}	—	—	—	—	—	—
Surface Resistivity	296	D-257	Ω	10^{15}–10^{16}	—	—	—	—	—	—	—	—
OTHER PROPERTIES												
Water Absorption		D-570	%									
24 hrs @ 296°K				.24	—	.19	—	.14	—	.21	—	.23
48 hrs @ 323°K				.72	—	.57	—	.42	—	.49	—	.65
Equilibrium–50% RH				1.0–1.3	1.0–1.3	0.8–1.1	0.8–1.1	—	—	—	—	—
Specific Gravity		D-792		1.43	1.34	1.51	1.42	1.65	1.56	1.55	1.46	1.60
Hardness		D-785	Rockwell "E"	45–60	—	25–45	—	5–25	—	1–20	—	40–55
Limiting Oxygen Index		D-2863	%	53	—	49	—	—	—	—	—	—

† Machined tensile specimens made per D-1708 and direct-formed specimens made per figure 19 of E-8 (standard bar for powdered metallurgy products); specimens tested by D-638.

* Direct-formed (DF) properties marked with asterisk were measured parallel to the forming direction. All other direct-formed properties were measured perpendicular to the forming direction. Machined (M) properties are non-directional.

†† Unlubricated in air (PV-.875 MPa m/s)).

** Steady state, unlubricated in air.

Stress-Strain Curves

Figures 1 and 2 show typical stress-strain curves in tension for machined SP polyimide parts at 73°F (296°K) and 500°F (533°K); Figures 3 and 4 show similar curves for direct-formed parts. The curves for a given composition differ between the two forms because of the lower density of the direct-formed parts.

Figures 5 through 7 provide data on stress-strain in compression. While you can load most SP polyimide compositions in compression to high strains (>30%) without reaching ultimate strength, in practice this would result in a grossly deformed part. The curves showing low strains (up to 5%) illustrate the practical limits of loading without significantly exceeding the elastic limits of the materials. Table 1 provides the compressive stress data circulated for 0.1% permanent deformation in the part. Unlike thermosetting materials, SP polyimide can be compressed several percent before reaching this deformation level. The materials are quite compliant and useful in forming seals of many types.

FIGURE 1

MACHINED SP POLYIMIDE
TYPICAL STRESS-STRAIN IN TENSION
AT 73°F (296°K), ASTM D1708

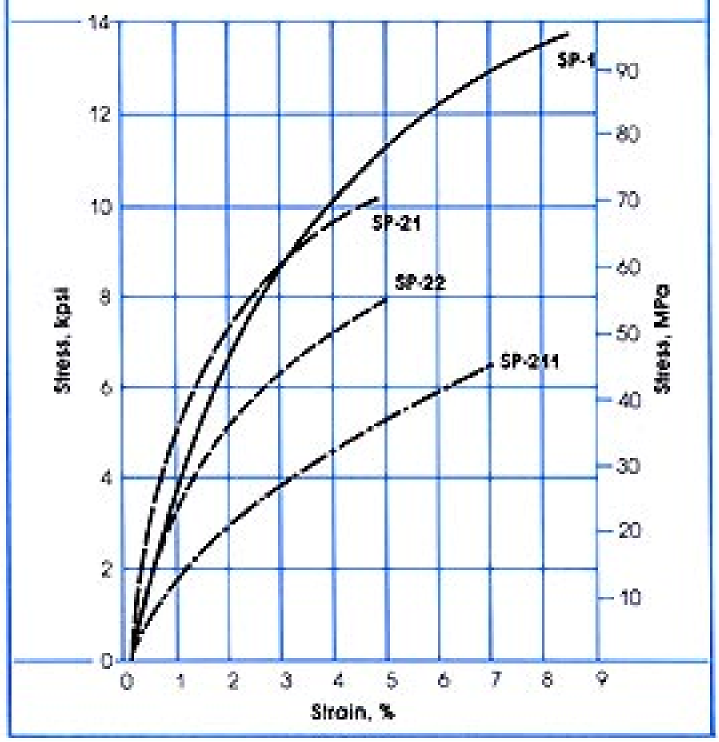


FIGURE 2

MACHINED SP POLYIMIDE
TYPICAL STRESS-STRAIN IN TENSION
AT 500°F (533°K), ASTM D1708

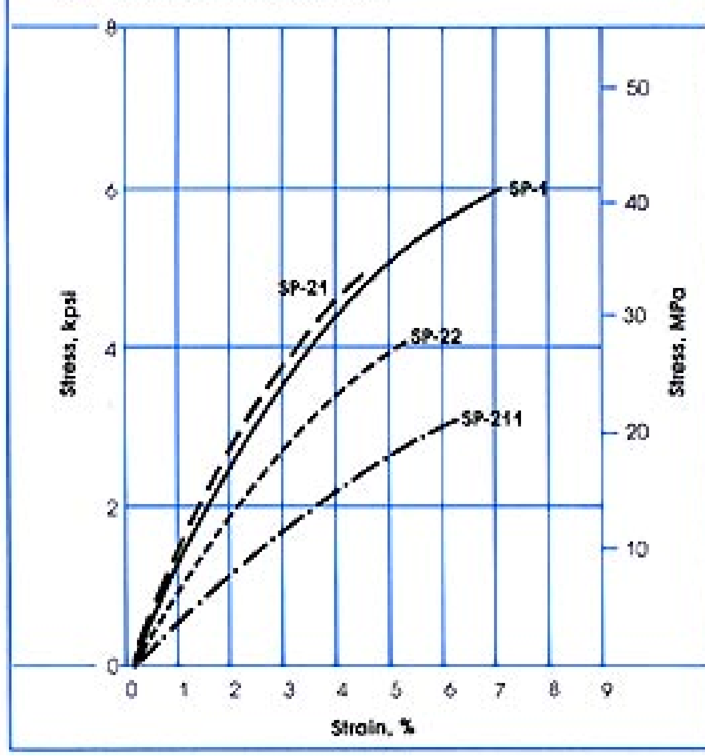


FIGURE 3

DIRECT-FORMED SP POLYIMIDE (⊥ TO FORMING)
TYPICAL STRESS-STRAIN IN TENSION
AT 73°F (296°K), ASTM E8

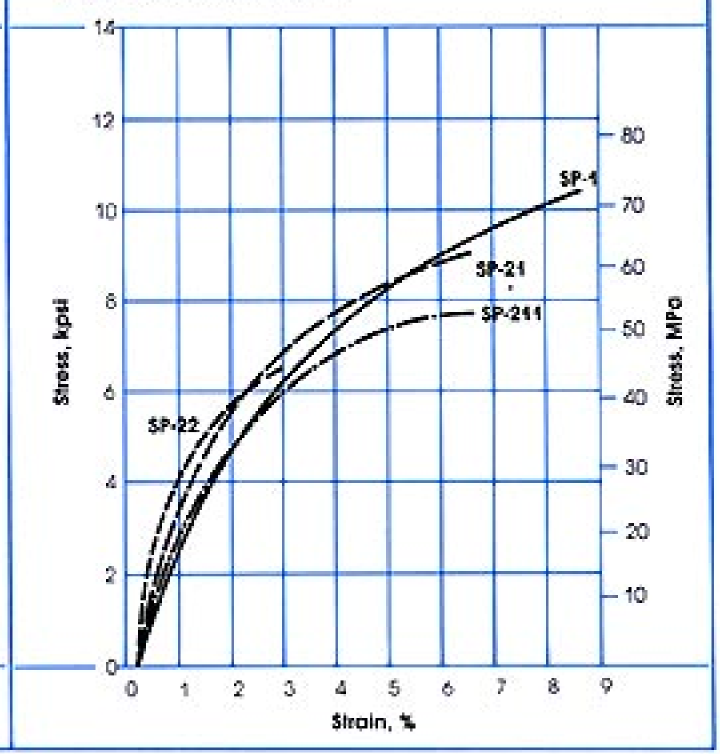


FIGURE 4

DIRECT-FORMED SP POLYIMIDE (⊥ TO FORMING)
TYPICAL STRESS-STRAIN IN TENSION
AT 500°F (533°K), ASTM E8

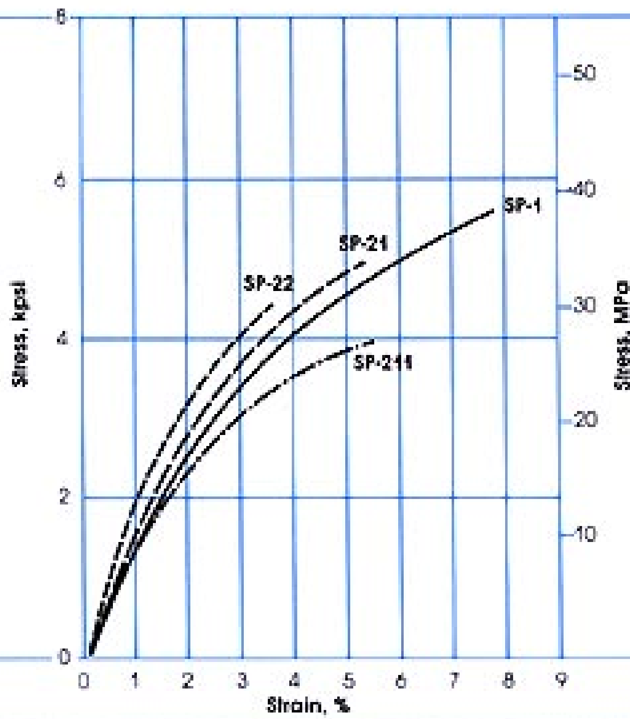


FIGURE 5

MACHINED SP POLYIMIDE IN COMPRESSION
AT 73°F (296°K), ASTM D-695

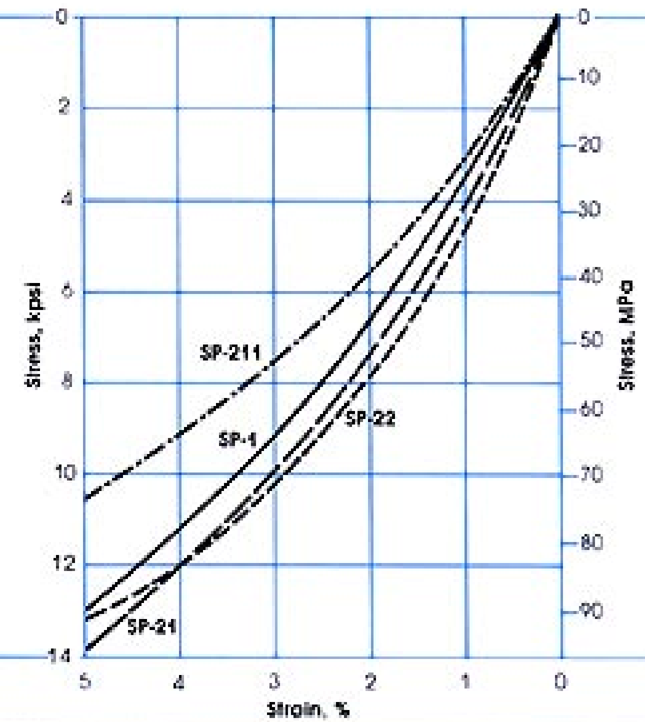


FIGURE 6

MACHINED SP POLYIMIDE IN COMPRESSION
AT 572°F (573°K), ASTM D-695

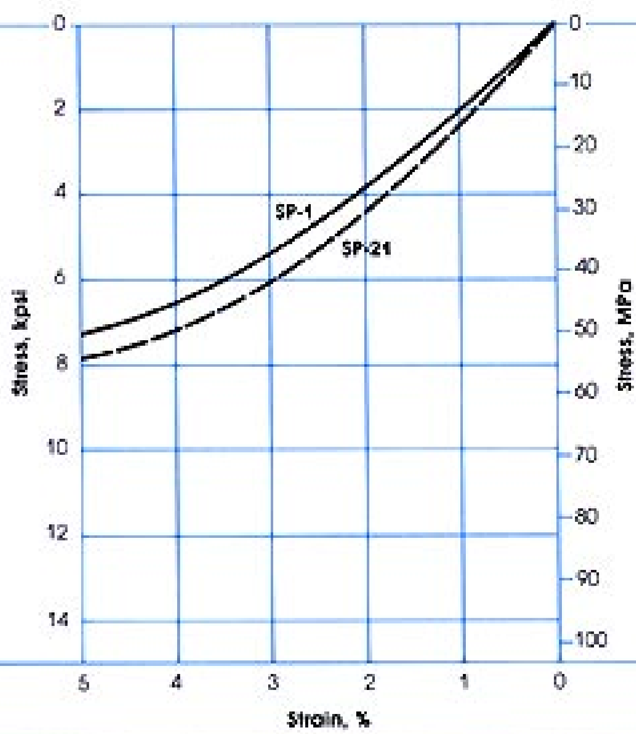
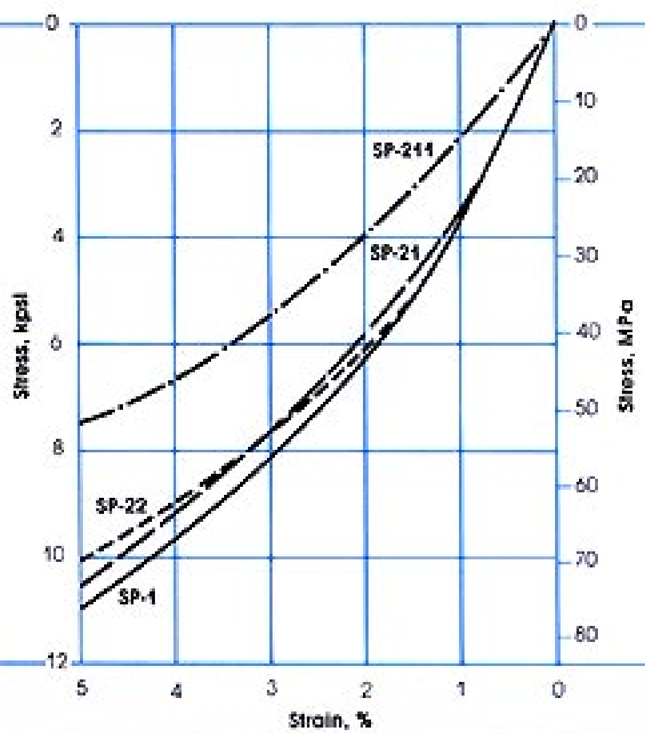


FIGURE 7

DIRECT-FORMED SP POLYIMIDE (II TO FORMING)
TYPICAL STRESS-STRAIN IN COMPRESSION
AT 73°F (296°K), D-695



Effect of Temperature

Since SP polyimide does not melt and has no glass transition temperature (Tg) or softening point as measured by the usual methods, strength and moduli decrease with temperature in a nearly linear manner. This contrasts to the usual engineering thermoplastic which shows a large decrease in these properties as the Tg is approached. Figures 8 through 11 illustrate typical changes in tensile strength and modulus of elasticity with temperature for machined and direct-formed parts.

The upper use temperature of SP polyimide is limited by its rate of degradation, not by a softening point where it would lose its load-carrying capability. Parts may be used continuously in air at 500°F (533°K) and for short excursions to as high as 900°F (755°K).

Figure 12 illustrates usefulness at high temperatures in terms of time to 50% reduction in initial tensile strength. For example, after 100 hours continuous exposure to air at 700°F (644°K), SP-1 polyimide will retain half its initial strength. The graphite filler in SP-21 and SP-22 polyimide imparts some physical stability to the parts which is manifested in a greater retention of properties with time. SP-21 (15% graphite) requires about 200 hours at 700°F (644°K) and SP-22 (40% graphite) 350 hours to reach the 50% strength level. The loss in properties with time at temperatures up to about 750°F (672°K) is due almost entirely to oxidative degradation. At temperatures up to at least 650°F (588°K), SP parts will perform in inert environments such as nitrogen or vacuum with negligible loss of properties with time.

FIGURE 8
MACHINED SP POLYIMIDE
TYPICAL ULTIMATE TENSILE STRENGTH vs. TEMPERATURE
ASTM D1708

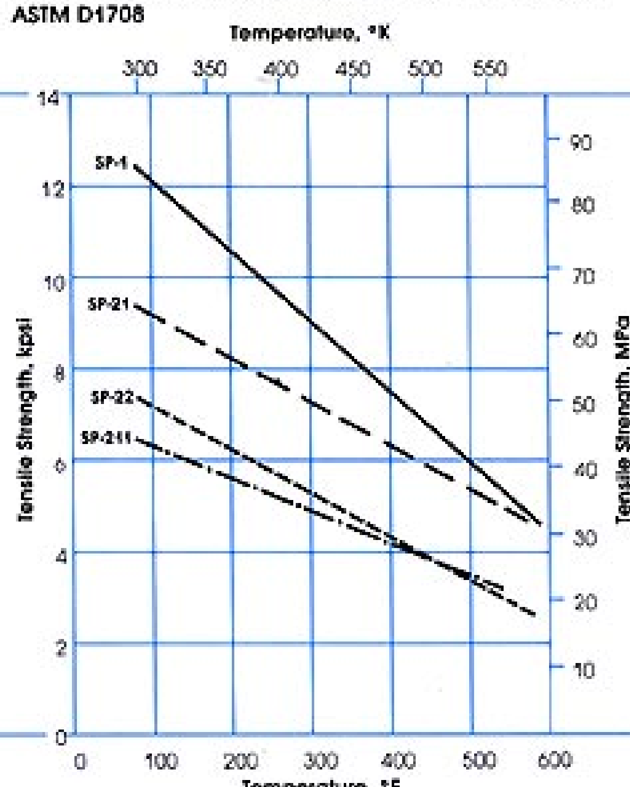


FIGURE 9
DIRECT-FORMED SP POLYIMIDE
TYPICAL ULTIMATE TENSILE STRENGTH vs. TEMPERATURE
ASTM E8

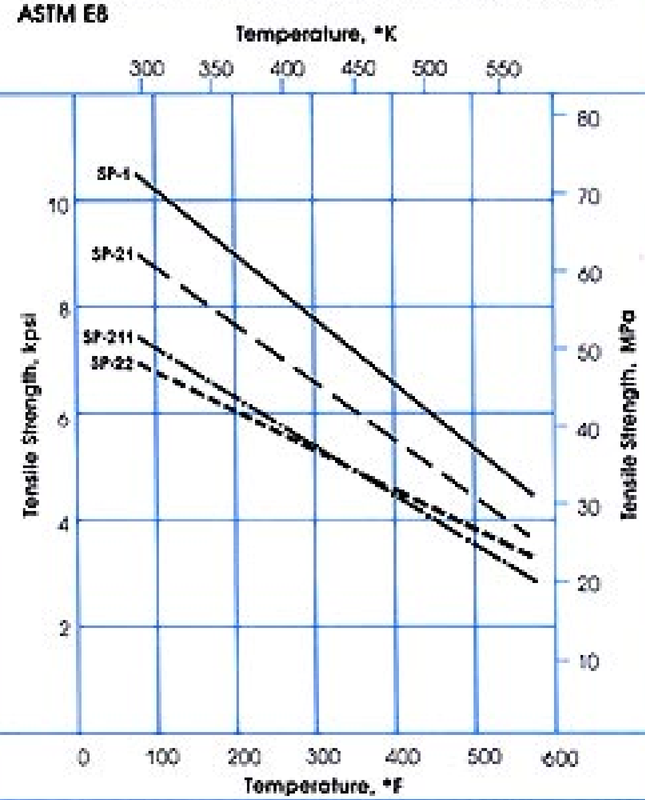


FIGURE 10
MACHINED SP POLYIMIDE
TYPICAL MODULUS OF ELASTICITY (FLEXURAL MODULUS)
vs. TEMPERATURE, ASTM D740

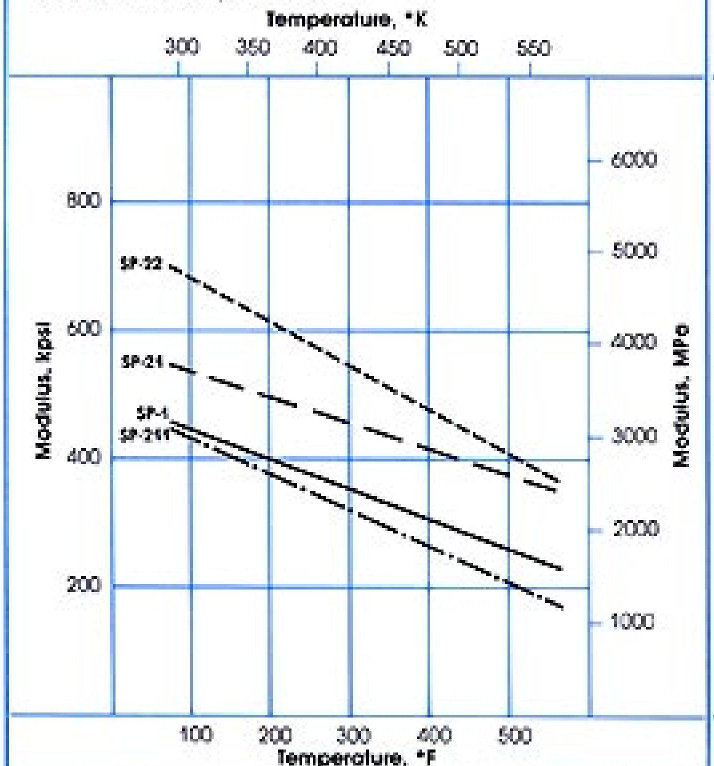


FIGURE 11
DIRECT-FORMED SP POLYIMIDE
TYPICAL MODULUS OF ELASTICITY (FLEXURAL MODULUS)
vs. TEMPERATURE, ASTM D790

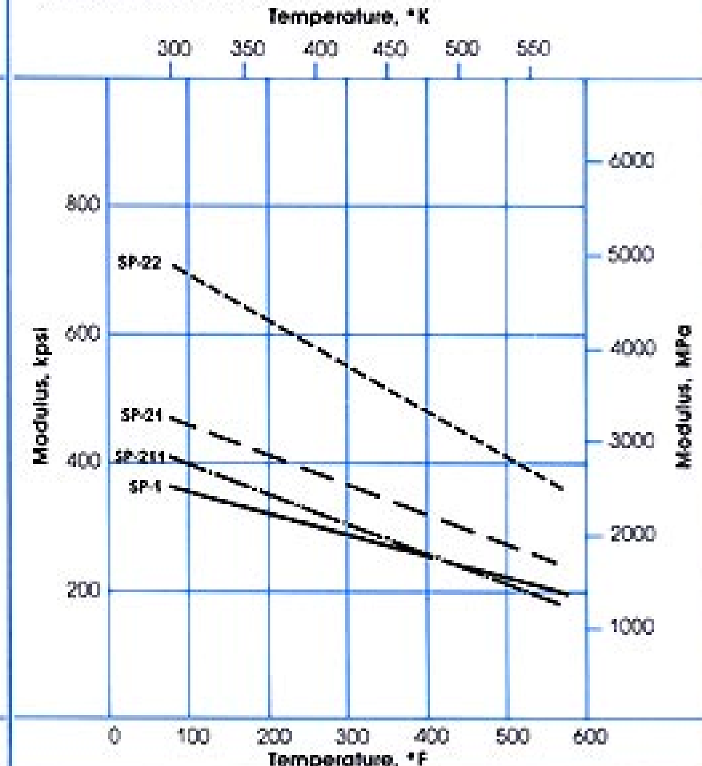
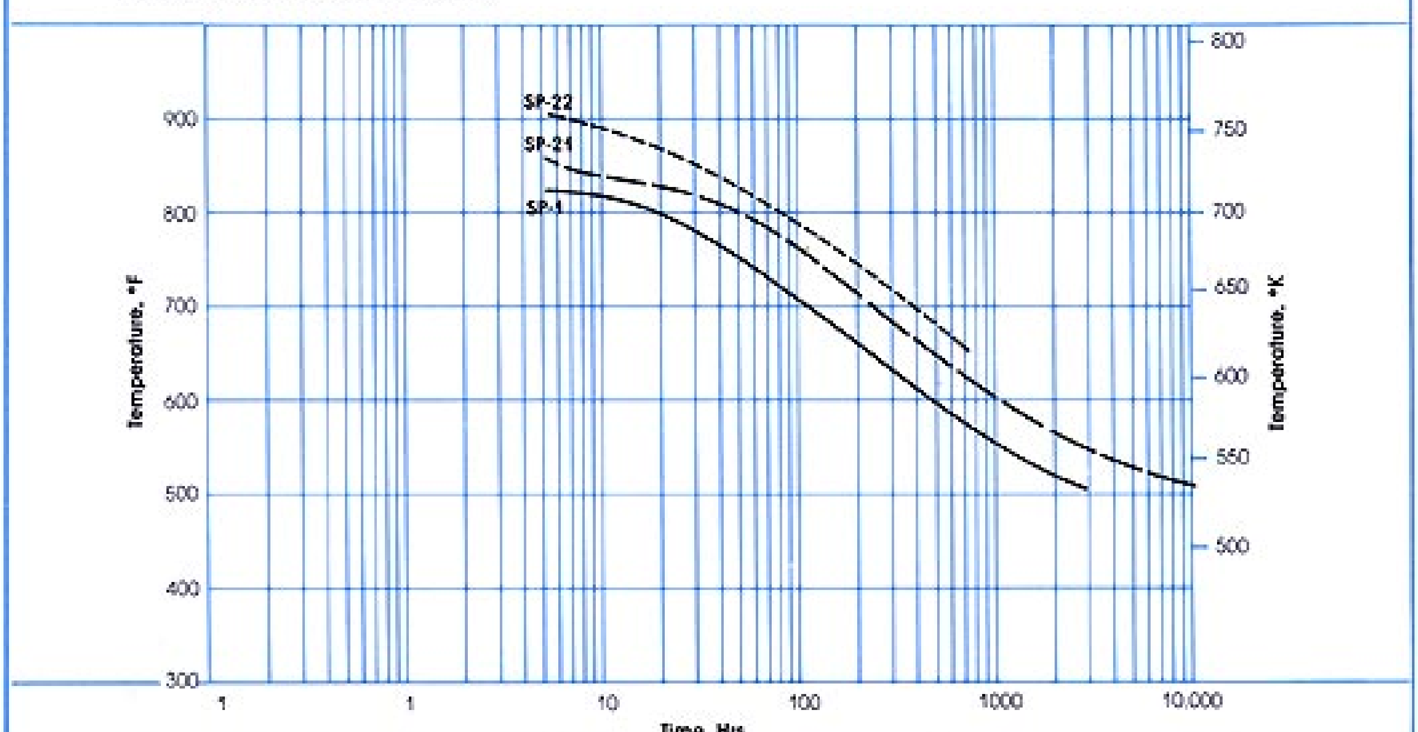


FIGURE 12
SP POLYIMIDE
EXPOSURE TO AIR AT ELEVATED TEMPERATURE
APPROXIMATE TIME TO 50% REDUCTION IN
TENSILE STRENGTH vs. TEMPERATURE



Creep and Stress Relaxation

The time-dependent deformation which occurs in a plastic material under constant stress is called creep.

Creep at a given time is the difference between the total strain at that time and the initial instantaneous strain experienced on loading.

The time-dependent decrease in the stress needed to maintain a constant strain is called stress relaxation.

Figures 13, 14 and 15 show total deformation or strain vs. time under 1500 and 2500 psi (10.3 and 17.2 MPa) for machined SP-1, SP-21 and SP-22 polyimide at two temperatures.

Since SP polyimide doesn't soften and is thermally resistant, it can carry loads at temperatures beyond the reach of most plastic materials and do so while exhibiting extremely low creep. Creep resistance is further enhanced in the graphite-filled compositions, SP-21 and SP-22. For example, Figure 15 shows that creep for SP-22 polyimide at 2500 psi and 572°F is only 0.5% after 1,000 hours.

FIGURE 13
MACHINED SP-1 POLYIMIDE
TOTAL DEFORMATION UNDER LOAD vs. TIME

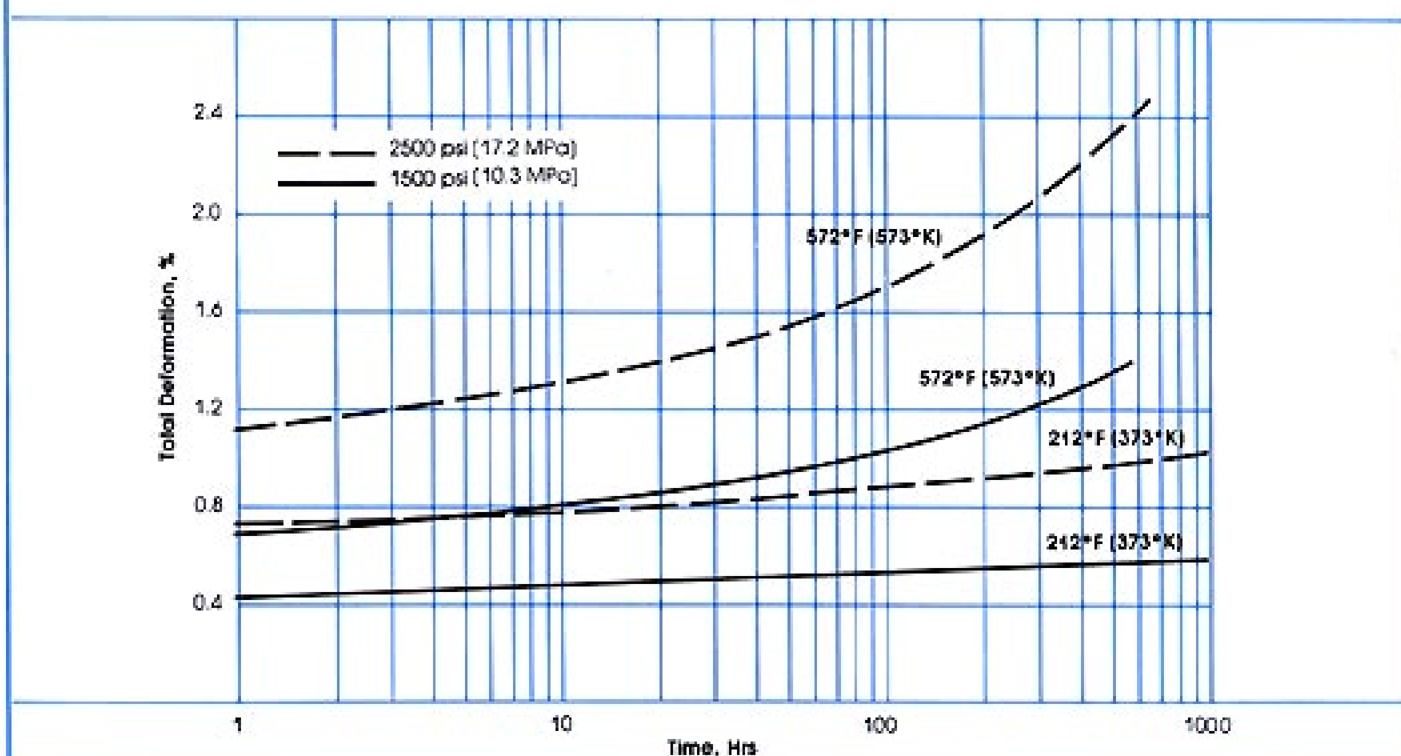


FIGURE 14

MACHINED SP-21 POLYIMIDE
TOTAL DEFORMATION UNDER LOAD vs. TIME

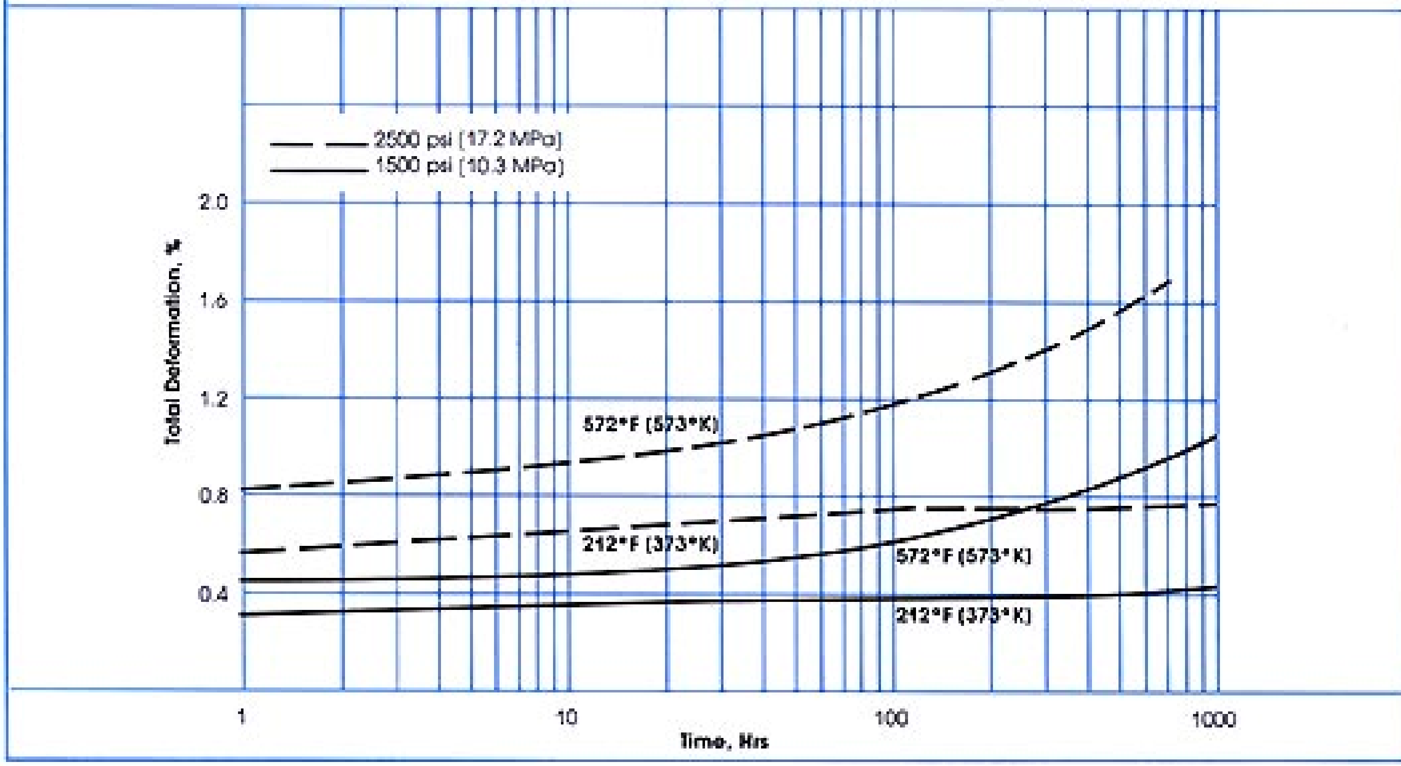
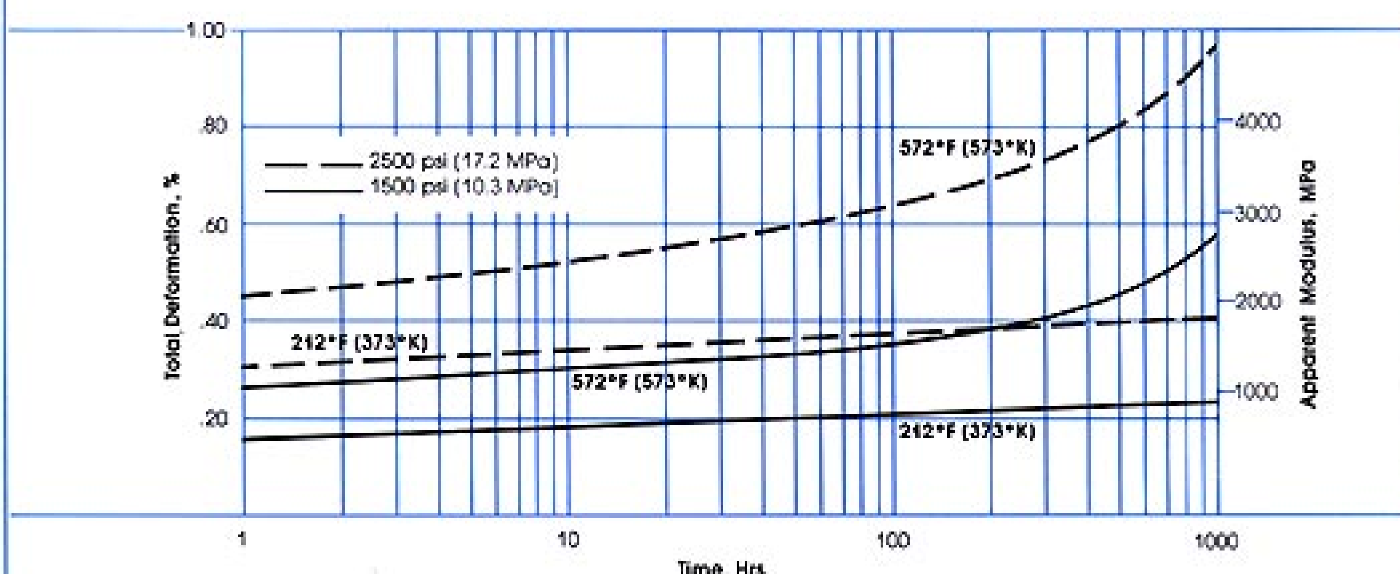


FIGURE 15

MACHINED SP-22 POLYIMIDE
TOTAL DEFORMATION UNDER LOAD vs. TIME



Figures 16 through 18 give the change in apparent modulus of elasticity with time corresponding to Figures 13 through 15. Substituting the appropriate time-dependent apparent modulus for elastic modulus in standard engineering equations will allow prediction of the effects of creep and stress relaxation.

FIGURE 16
MACHINED SP-1 POLYIMIDE
APPARENT MODULUS vs. TIME UNDER LOAD

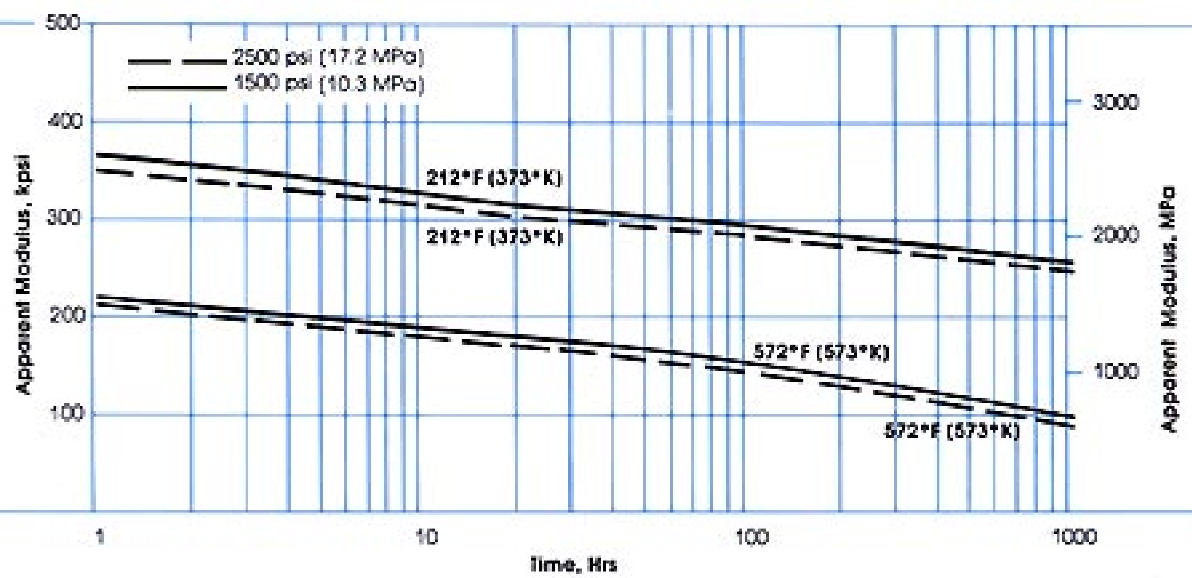


FIGURE 17

MACHINED SP-21 POLYIMIDE
APPARENT MODULUS vs. TIME UNDER LOAD

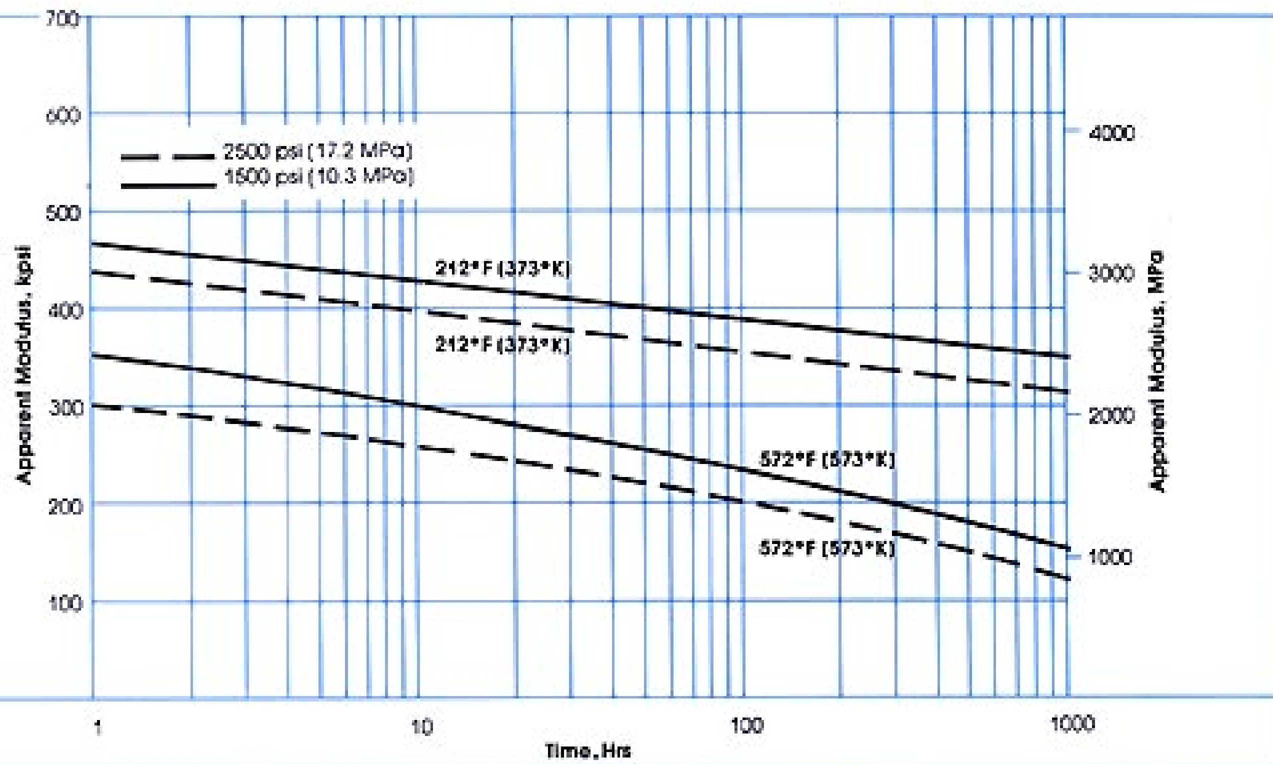
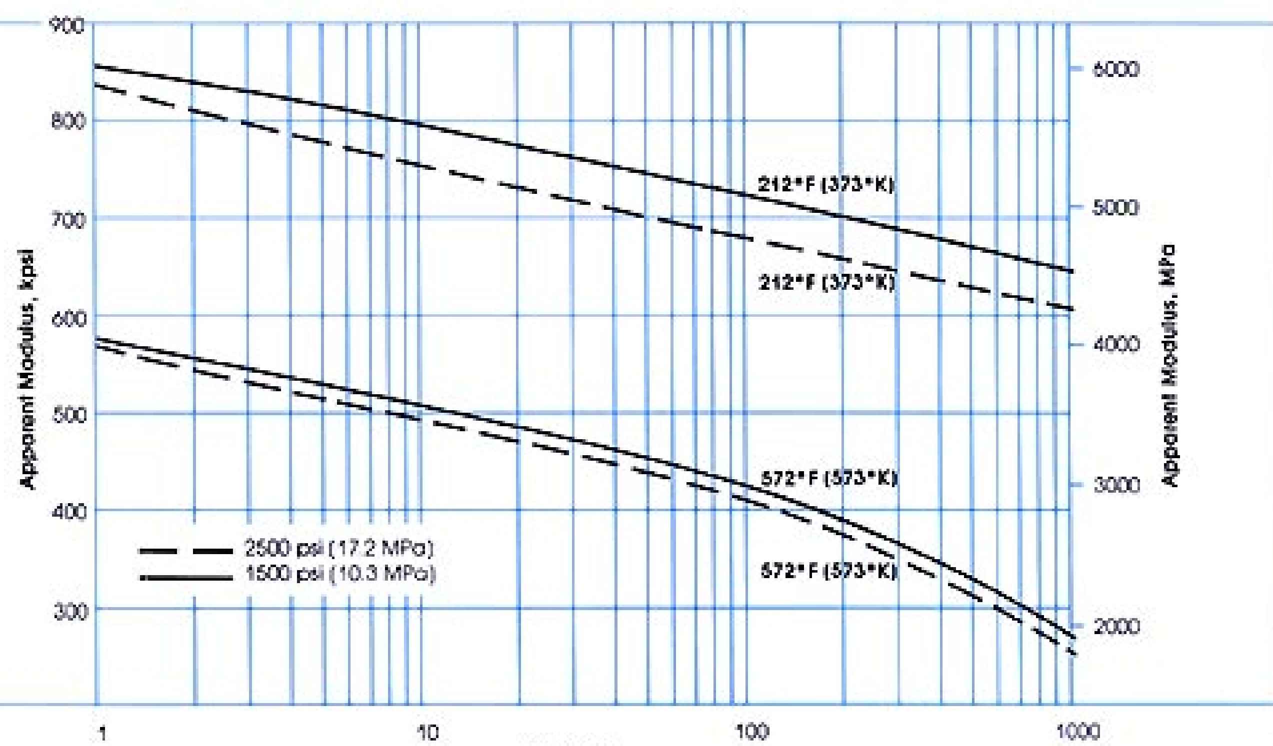


FIGURE 18

MACHINED SP-22 POLYIMIDE
APPARENT MODULUS vs. TIME UNDER LOAD



Effect of Moisture Absorption

Figures 19 through 21 illustrate typical rates of dimensional change caused by moisture absorption for machined and direct-formed parts made of SP polyimide. Time to reach equilibrium moisture content from the dry state in a controlled environment is very long, involving thousands of hours. Since the absorption of moisture is diffusion controlled, the rate is inversely affected by the minimum dimension of the part.

Figures 22 and 23 show typical effects of relative humidity (RH) changes at 73°F (296°K) on the dimensions of machined and direct-formed parts. A part attains its full dimensional change at a given humidity level only after it has reached equilibrium in the particular environment. Allowing a completely dry part to reach equilibrium at 100% RH at 73°F (296°K) will result in a maximum change of about 0.5% or .005 in/in (mm/mm).

FIGURE 19
MACHINED SP-1 AND SP-21 POLYIMIDE
TYPICAL DIMENSIONAL CHANGE vs TIME AT 73°F (296°K), 50% RH, 1/8 IN. (3.2mm) PLAQUES

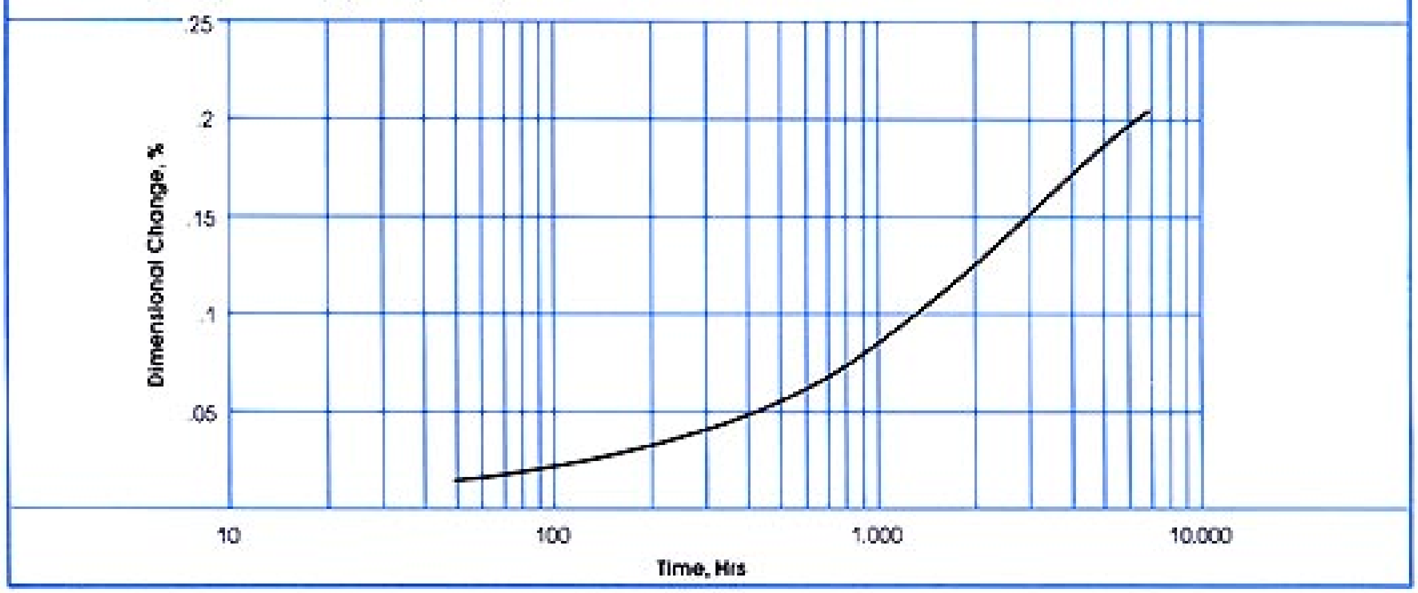


Figure 20
DIRECT-FORMED SP-1 POLYIMIDE
TYPICAL DIMENSIONAL CHANGE WITH TIME AT 50 AND 100% R.H., 73°F (296°K)
1 IN. (25mm) DIA. DISCS, 0.1 IN. (2.5mm) THICK

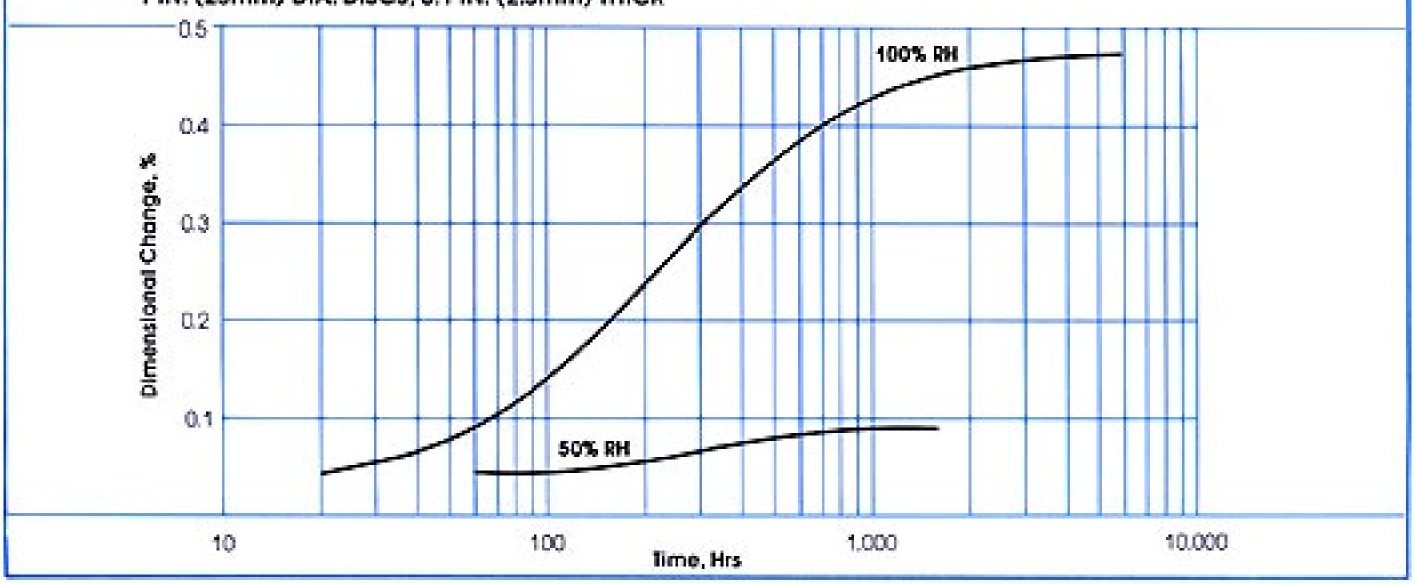


FIGURE 21

DIRECT-FORMED SP-21 POLYIMIDE
TYPICAL DIMENSIONAL CHANGE WITH TIME AT 50 AND 100% R.H., 73°F (296°K)
1 IN. (25mm) DIA. DISCS, 0.1 IN. (2.5mm) THICK

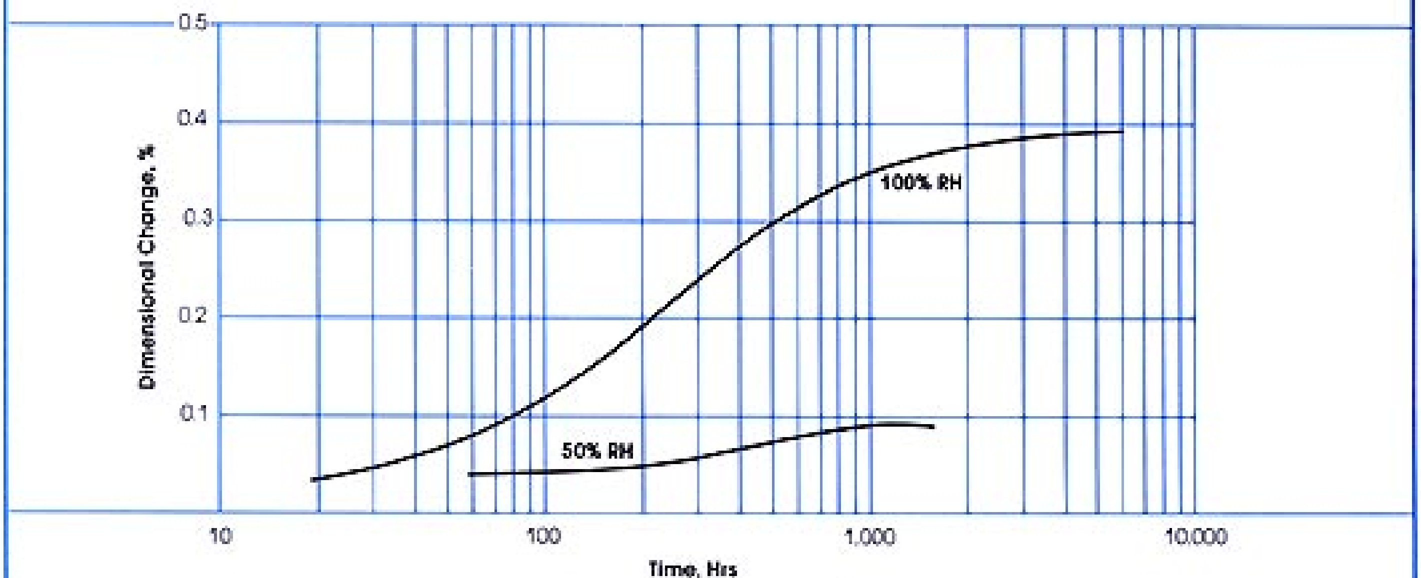


FIGURE 22

MACHINED SP-1 AND SP-21 POLYIMIDE
TYPICAL DIMENSIONAL CHANGE WITH RELATIVE HUMIDITY AT EQUILIBRIUM, 73°F (296°K)

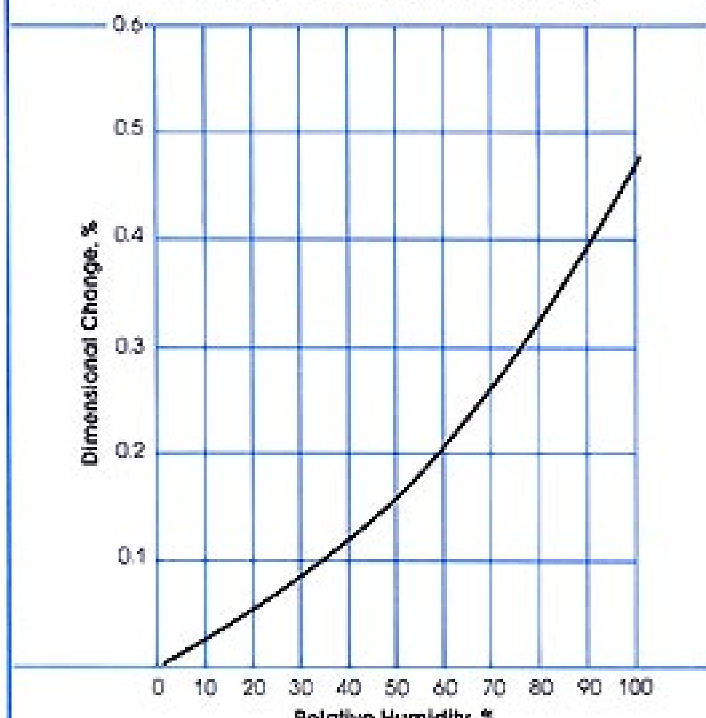
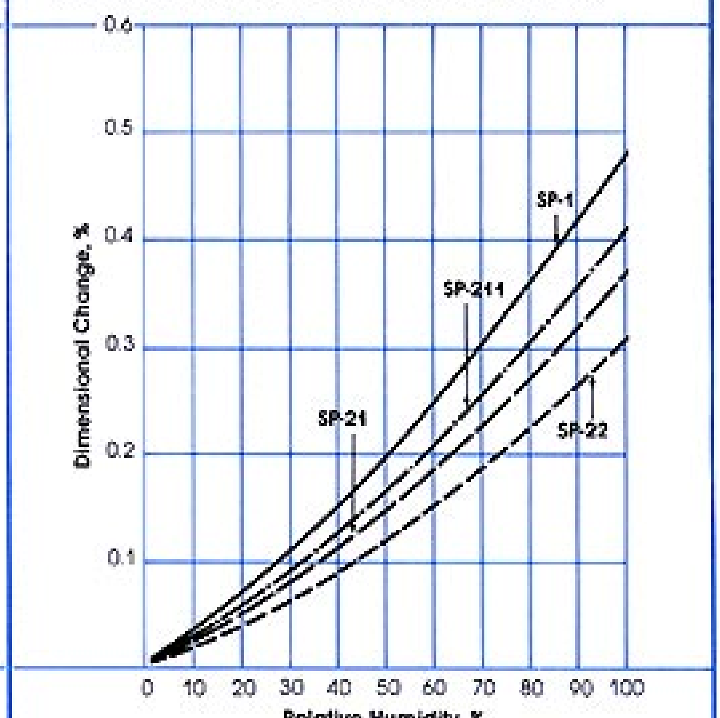


FIGURE 23

DIRECT-FORMED SP POLYIMIDE
TYPICAL DIMENSIONAL CHANGE WITH RELATIVE HUMIDITY AT EQUILIBRIUM, 73°F (296°K)



Thermal Expansion

Linear dimensional change with temperature is shown in Figure 24 for machined SP polyimide and in Figure 25 for direct-formed polyimide. Each plot contains the average coefficient of thermal expansion over the temperature range 73°–572°F (296°–573°K) in both British and SI units. The coefficient over any other range of temperature may be slightly different and can be determined from the curves by dividing the percent dimensional change over the desired range by 100 × the temperature differential in degrees (ΔT).

For all compositions, thermal expansion of direct-formed parts is lower than for machined parts—a result of the "directionality" of direct-formed parts, as discussed earlier.

The addition of graphite filler reduces thermal expansion. Thus, SP-21 and SP-22 polyimide offer a lower expansion than unfilled SP-1. The coefficient of thermal expansion of SP-22 approaches that of aluminum.

Fatigue and Impact Resistance

Failure of materials at stress levels lower than their ultimate tensile strengths when the applied stress is repeated cyclically is known as fatigue failure. A plot of stress to cause failure at 10^5 to 10^7 cycles vs. temperature to 500°F (533°K) is shown in Figure 26 for machined SP-1 and SP-21. Stress was applied by alternating tension and compression at 1800 cycles per minute. At this frequency there is little or no effect of overheating of the specimen which could cause premature failure.

Although fatigue data obtained through testing procedures can be used as a guide in designing parts, they should not be used without considering environment and stress concentrations. While test specimens usually have smooth surfaces, the presence of notches, scratches, holes or sharp corners can cause concentration of stress. No fatigue tasting is a substitute for actual or simulated end-use testing of a part.

Impact resistance is difficult to predict since the geometry of the part, stress concentrations and the rate of loading all have an effect. To increase impact resistance, parts should be designed to obtain the maximum area of load application. Designing a part for maximum flexibility will also help by increasing the distance over which impact energy is expended.

SP polyimide, like most other plastics, displays notch sensitivity as shown by the values of notched Izod impact strength shown in Table 1 (page 4). As with most materials, avoid designing sharp corners and other stress raisers into the part.

FIGURE 24
MACHINED SP POLYIMIDE
LINEAR THERMAL EXPANSION
ASTM D-696

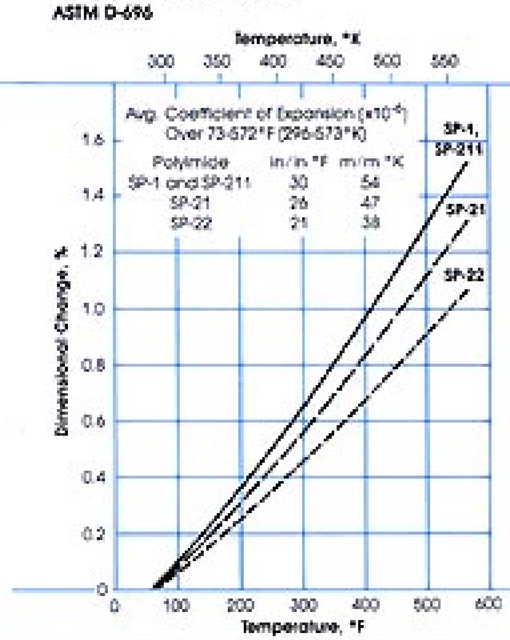
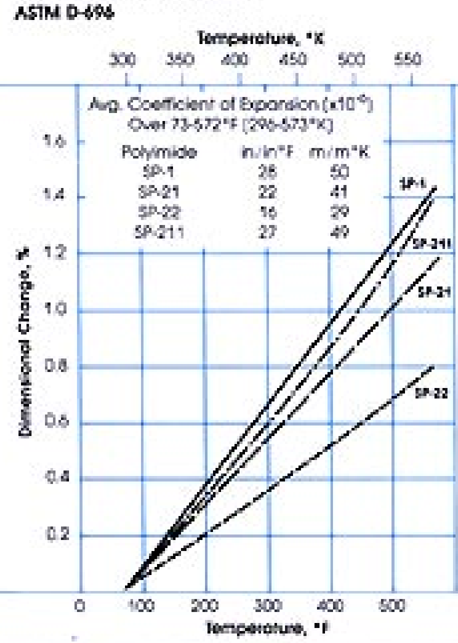


FIGURE 25
DIRECT-FORMED SP POLYIMIDE (⊥ TO FORMING)
LINEAR THERMAL EXPANSION
ASTM D-696



Chemical Effects

Vespel SP parts perform well in a variety of chemical environments. The tensile strength data shown in Table 3 were determined using exposure tests patterned after ASTM Method D543-67, “Resistance of Plastics to Chemical Reagents.”

Organic Solvents

In general, exposure to solvents for prolonged periods over a wide temperature range does not affect the mechanical and dimensional properties of **Vespel** parts. Chlorinated and fluorinated solvents such as FREON® fluorocarbon, can be used for surface cleaning of **Vespel** parts as long as adequate ventilation exists.

At elevated temperatures some hydrocarbon solvents containing functional groups, such as M-cresol and nitrobenzene, can cause SP polyimide parts to swell; however, **Vespel** parts are suggested for service in a variety of industrial fluids (fuels, oils, lubricants) at elevated temperatures. Generally, **Vespel** parts exposed to the fluids detailed in Table 3 exhibit no significant change in dimensions or mechanical properties. However, the compositions of industrial fluids differ among manufacturers and can vary over time with any single manufacturer. Testing is recommended for each proposed use of **Vespel** parts to provide quantitative guidance on the effect of the specific environment.

Aqueous Media

SP polyimide parts can be exposed to water up to 212°F (373°K), provided the stresses are low enough to take into account the reduced mechanical properties. At 212°F (373°K), the tensile strength and elongation of SP polyimide parts are reduced to 45% and 30% of the original values, respectively, in about 500 hours, at which point they level out. Some of the reduced tensile properties caused by moisture absorption may be restored by drying.

FIGURE 26

MACHINED SP POLYIMIDE TYPICAL FATIGUE RESISTANCE vs. TEMPERATURE REVERSED TENSILE AND COMPRESSIVE STRESS @ 1800 CYCLES/MIN (30 Hz)

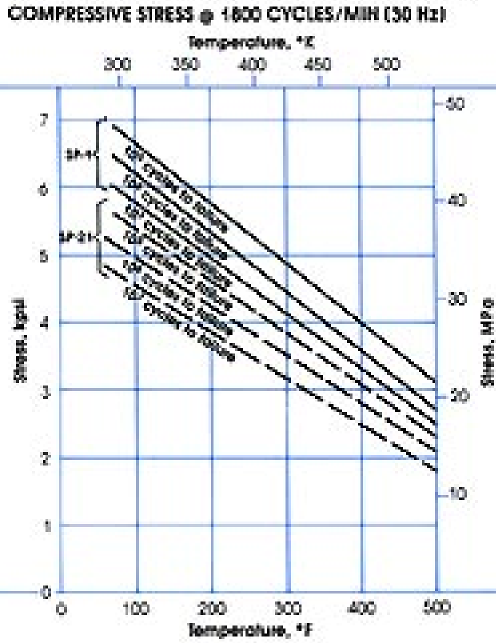


TABLE 3

Chemical Media	°F	°K	Time Hrs.	% Tensile Strength Retained by SP-1
Organic Solvents				
M-Cresol	400	477	1,000	75(1)
o-Dichlorobenzene	355	452	1,000	100
Diethyl ketone	210	372	1,900	100
Ethanol	210	372	1,900	100
Nitrobenzene	420	488	1,000	85(1)
Perchloroethylene	210	372	1,900	100
Toluene	210	372	1,900	100
Industrial Fluids				
Hydraulic Fluid (Skydrol”), Polyphosphate ester	248	393	1,000	100
JP-4 Jet Fuel	210	372	1,900	80
Jet Engine Oils (MIL L7808 G, Type 2)	500 500	533 533	600 1,000	60 (90)(2) 30 (60)(2)
Mineral Oil	392	473	1,000	70 (90)(2)
Silicone fluid	500	533	1,000	70 (85)(2)
Ticresyl phosphate (oil additive)	500	533	1,000	80
Acids				
Acetic, 15%	210	372	1,900	20
Hydrochloric, 38%	73	296	120	70
Hydrochloric, 5%	210	372	1,900	15
Nitric, 70%	73	296	120	40
Bases				
Sodium Hydroxide, 5%	73	296	120	55
Oxidizing Agents				
Nitrogen Tetroxide	73	296	120	60

(1) Swelling.

(2) SP-21 polyimide (15% graphite-filled).

As with all polyimides, SP polyimide resin is subject to hydrolysis. Cracking may occur on prolonged exposure to water or steam at temperatures exceeding 212°F (373°K). Actual end-use testing should be conducted for applications involving such exposure.

Aqueous salt solutions will have the same effect on SP polyimide parts as water.

Bases

SP polyimide parts are susceptible to alkaline attack, which leads to a loss of mechanical properties. Exposure to ammonia and hydrazines (anhydrous liquids or vapor), primary and secondary amines, and solutions having a pH of 10 or more must be avoided.

Oxidizing Agents

Chemical reagents which act as powerful oxidizing agents (i.e., nitric acid, nitrogen tetroxide, etc.) can cause oxidation of **Vespel** parts. Weaker agents will require end-use testing.

Oxygen Compatibility

SP-21 (15% graphite-filled) is compatible with liquid and gaseous oxygen systems. The National Aeronautics and Space Administration tested the material, which meets MSFC-SPEC-106B, “Testing Compatibility of Materials for Liquid Oxygen Systems”. At the present time this approval is on a selected-lot basis.

Similarly, SP-21 was tested by the Naval Air Engineering Center, U.S. Navy, and was found compatible according to MIL-V-5027C, “Non-Metallic Materials Compatible with Oxygen.”

Other filled SP polyimide compositions should also meet these specifications but none have been tested to date. The unfilled resin, SP-1, does not meet these standards.

Electrical Properties

The combination of good electrical properties, high strength, and excellent thermal and radiation resistance makes unfilled **Vespel** parts outstanding candidates for electrical applications in severe environments. More importantly, **Vespel** parts retain their electrical properties at high temperatures.

Figure 27 shows a decreasing dielectric constant for SP-1 polyimide with temperature at frequencies from 10^2 to 10^5 Hz. The change reflects a reduction of absorbed moisture with increasing temperature. Dried specimens have a dielectric constant of 3–3.1 over the temperature range. Likewise, the dissipation factor (Figure 28) of a dried specimen is about .001 at the lower temperatures. Moisture content has relatively little effect of resistivity.

Volume and surface resistivities of SP-1 decrease with increasing temperature (Figures 29 and 30). The graphite-filled compositions are not recommended for electrical applications although high resistivity values have been obtained with parts produced from them. If graphite is exposed on the surface of the parts as formed or machined, resistivity can decrease quite dramatically.

Figures 31 and 32 show the dielectric strength of machined SP-1 as a function of air temperature and sample thickness.

The corona resistance of SP-1 is superior to that of fluorocarbons and polyethylenes. For example, at 200 v/mil (60 Hz and room temperature), corona life is 2200 hours.

FIGURE 27
MACHINED SP-1 POLYIMIDE
DIELECTRIC CONSTANT vs. TEMPERATURE, ASTM D-150

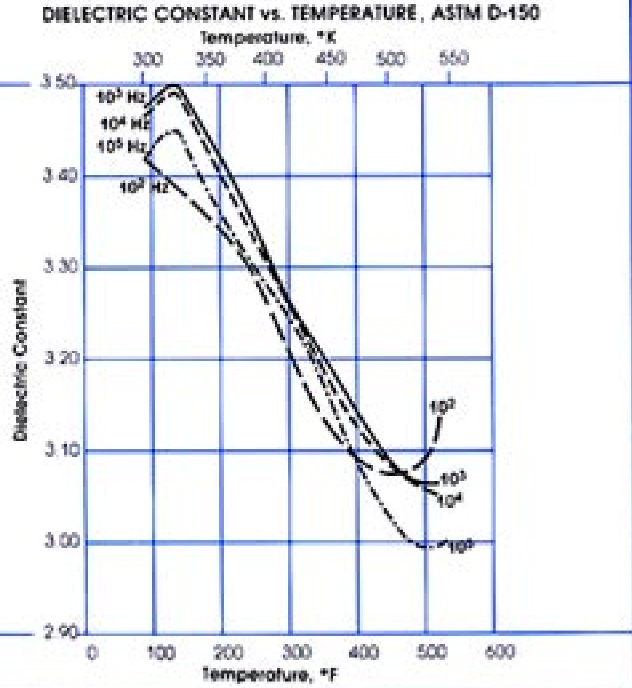


FIGURE 28
MACHINED SP-1 POLYIMIDE
DISSIPATION FACTOR vs. TEMPERATURE, ASTM D-150

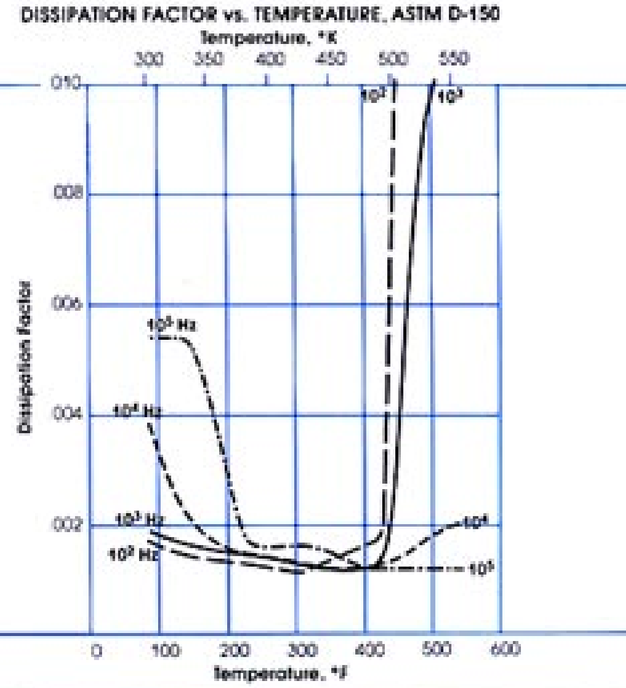


FIGURE 29

MACHINED SP-1 POLYIMIDE
VOLUME RESISTIVITY vs. TEMPERATURE, ASTM D257

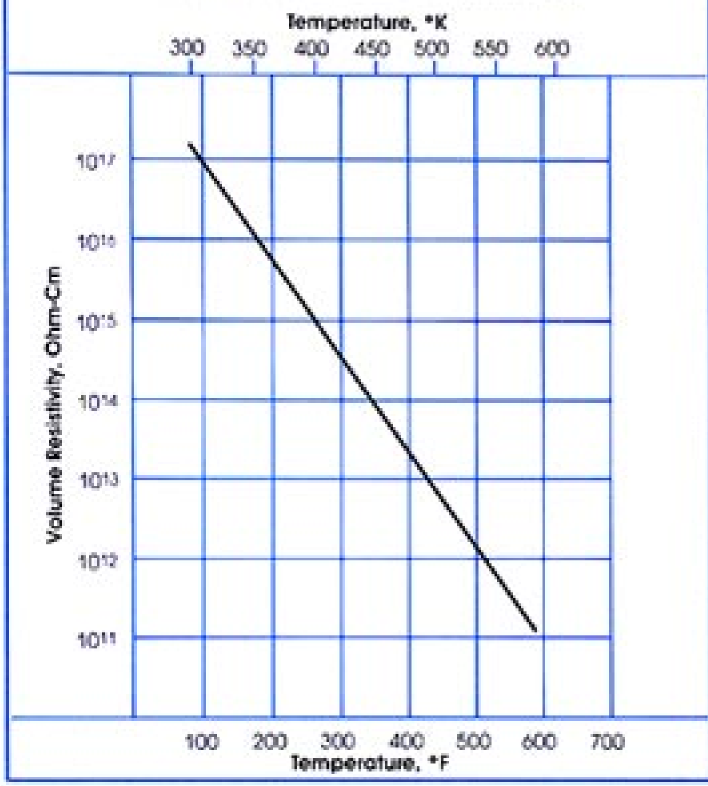


FIGURE 30

MACHINED SP-1 POLYIMIDE
SURFACE RESISTIVITY vs. TEMPERATURE, ASTM D257

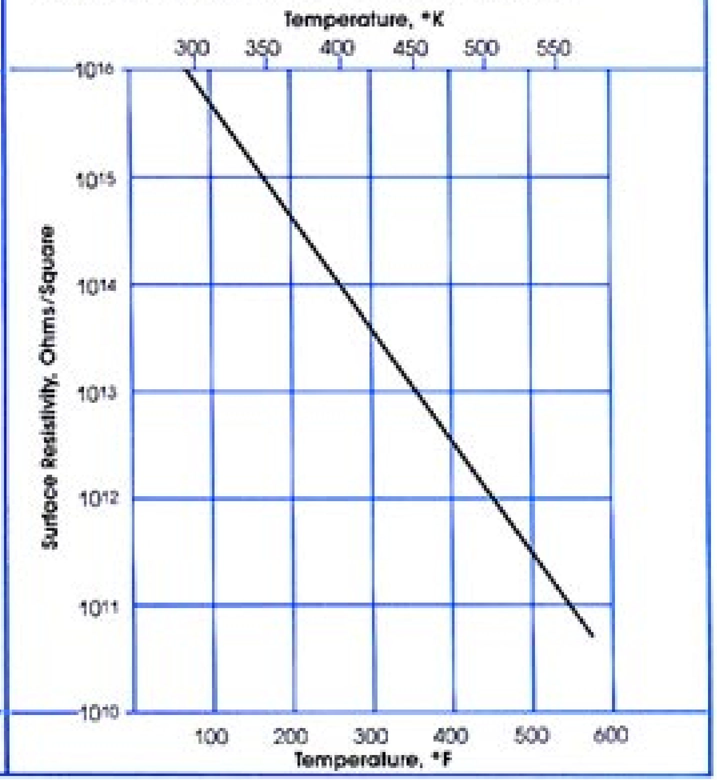


FIGURE 31

MACHINED SP-1 POLYIMIDE
DIELECTRIC STRENGTH vs. TEMPERATURE IN AIR, ASTM D149

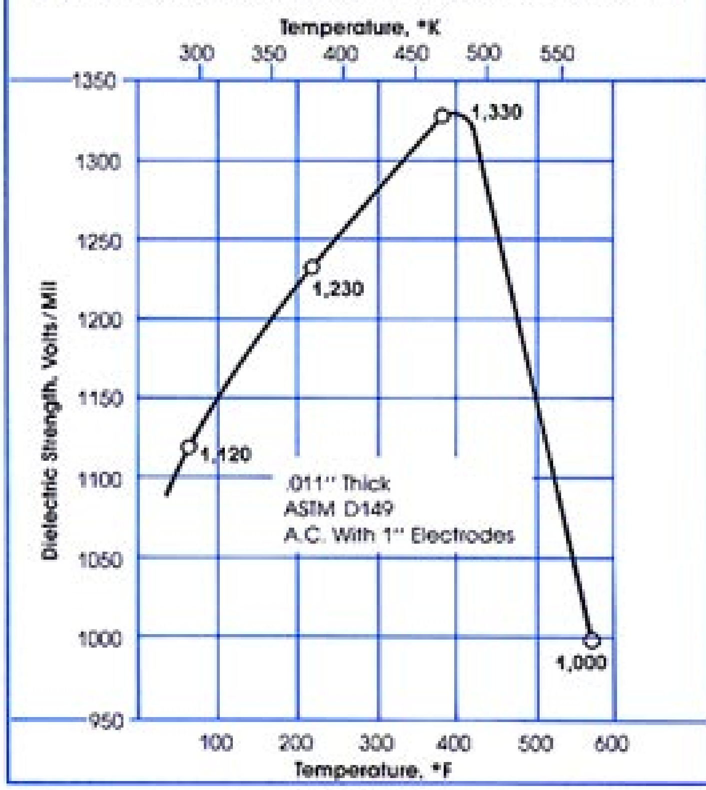
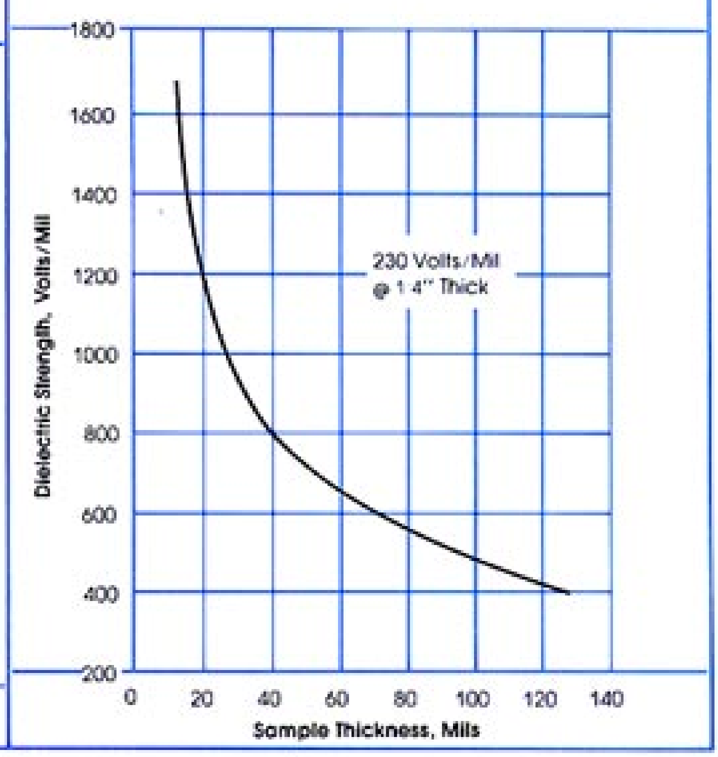


FIGURE 32

MACHINED SP-1 POLYIMIDE
DIELECTRIC STRENGTH vs. THICKNESS, ASTM 149—IN A-8 OIL



Other Properties

Weathering

SP polyimide parts undergo some loss of tensile strength and elongation after prolonged outdoor exposure and should be considered for such applications only after suitable testing. **Vespel** parts are completely resistant to fungus attack and test specimens have met the requirements of MIL.E 5272 and of federal specification CCC-T-191 b, Methods 5762 and 5751, for resistance to mildew and rot.

Radiation Resistance

Vespel parts have outstanding resistance to high energy, ionizing radiation. A test sample prepared from unfilled SP polyimide, irradiated in a 2MEV Van de Graff beam at an intensity of 10 watts/cm^2 (absorbed dose of 4 x 10^9 rads), showed no significant change in tensile strength, elongation or appearance. After 1500 hours in the Brookhaven Pile at 175°C (488°K), giving an absorbed dose of about 10^{11} rads, the SP polyimide sample was embrittled but still form-stable.

Toxicological Aspects

No toxicological effects attributable to SP polyimide were found in laboratory animals exposed to the resin by inhalation, ingestion or skin application. Application has not been made for approval by the Food and Drug Administration for use of **Vespel** parts in contact with food products.

SP polymer is extremely heat-stable compared to most organic materials but can yield carbon monoxide (CO) as a product of combustion. To make sure the CO concentrations remain below the acceptable safe level, care should be taken to provide adequate ventilation where **Vespel** parts are exposed to elevated temperatures in confined locations.

Outgassing

Once absorbed moisture has been removed from **Vespel** parts, weight loss in vacuum at high temperatures is low. In tests run by NASA at the Lewis Research Center, samples first dried at 200°F (366°K) gave a weight loss rate of less than 10^{-10} grams/cm^2/sec. at temperatures below 500°F. At 600°–700°F (500°–644°K) the weight loss rate was 10^{-7} grams/cm^2/sec.

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