VESPEL®
S
L I N E

DESIGN
HANDBOOK

DuPont™ Vespel®
forward engineering

DUPONT®

The miracles of science™

Design information on VESPEL®

Table of contents

Introduction

General

A number of recent innovations in both product and development and fabrication technology have led to a family of polyimide products that offer the design engineer practical, cost-competitive solutions to difficult problems in high temperature applications.

Commercial for more than 20 years, VESPEL® SP Parts and Shapes are particularly adapted to applications where thermal stability, electrical properties, wear and friction behaviour are required in mechanical components.

In addition to these semi-crystalline products, a new VESPEL® ST family, where the lack of crystalline structure is the major difference with SP, has been recently introduced to further increase strength and toughness.

From these polyimide resins DuPont fabricates VESPEL® parts to customers' exact specifications. Stock shapes are also available for machining prototypes and small quantities.

Today's competitive markets place a high 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. So the purpose of this manual is to help designers apply these principles to the selection, testing and specification of VESPEL® parts.

This design manual contains comprehensive physical property and performance data on the SP polyimide resins from which VESPEL® parts are made. Selection of data for this manual has been based to some extent on discussion with customers' design engineers involved with applications of VESPEL® parts. All of the data in the sections that follow are the result of extensive physical property research in DuPont laboratories in Wilmington, Delaware*.
Nevertheless end-use testing is always recommended.

Today VESPEL® parts are produced in Newark, USA; Utsunomiya, Japan; and Mechelen, Belgium.

Chemistry

Polymer

VESPEL® is a condensation type polyimide produced from pyromellitic dianhydride (PMDA) and 4,4′ diamino diphenyl ether (ODA).

VESPEL® has no observable glass transition temperature or melting point below a decomposition temperature that is well in excess of 400°C.

® Registered trademark of E.I. du Pont de Nemours and Company.
* Currently mentioned with references to ASTM methods, values will be indicated according to ISO specifications in the next revised Design Handbook.
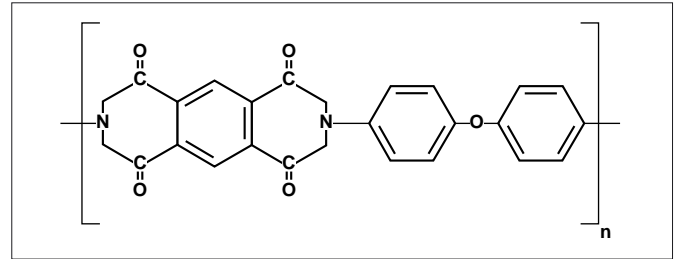
SP Polyimide

Fig. 1 **Chemical formula of VESPEL® SP**

This lack of glass temperature or melting point is a key feature in product performance. Therefore VESPEL® performs like thermosets.

The major difference between the polyimide resin, designated SP, and the new, designated ST, is the crystalline structure in the ST resin. Typical SP resins have a crystalline content estimated to be between 25 and 50%.

ST has little or no crystallinity. The infrared spectra for this resin, however, unlike the 40% imidized SP amorphous resin, has an imide content near 100%.

Fabrication methods

DuPont fabricates VESPEL® precision parts by several basic production methods. The method ultimately chosen is based on a number of considerations – end-use requirements, customer specifications, part geometry and economics.

Small quantities of parts and those of a large and / or complex shape are usually machined from rods, plaques or tubes. Thus, all standard metalworking techniques can be employed and very close tolerances can be held.

Larger quantities of parts, geometry permitting, can be direct-formed by a technique similar to powder metallurgy. Direct-formed parts usually can be produced at substantially lower prices than machined parts. Where specific part tolerances or complexity exceed the capability of the direct-forming method, a combination of direct forming and secondary machining is often used.

Properties vs. Direction

In common with most plastics, VESPEL® parts exhibit anisotropy or differences in properties depending on the direction of force used in fabrication. For example, properties such as tensile strength and elongation are higher and thermal expansion lower in the plane perpendicular (⊥) to the moulding force than in the direction parallel (∥) with the force.

VESPEL® parts machined from shapes usually do not show this effect.

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.

Direct-formed parts are produced with the pressure applied unidirectionally, resulting in some anisotropy, or directionally, 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.

It is very important, testing VESPEL® in an application, to use the material (either shape or direct formed) that will be used commercially. For this reason DuPont offers direct formed material (slugs) for prototyping.

Guide to meaningful specifications/needs

The establishing of specifications usually follows several other key steps in developing a new application for VESPEL® precision parts. Defining the end-use requirements is a necessary first step.

Drafting the preliminary design, preparation of prototypes and testing the design are steps that normally follow. Only after successful completion of these major steps should the question of writing specifications be examined.

The purpose of a specification is to avoid significant variations in the parts that would prevent them fulfilling the functional and economic criteria established in previous steps. The specification – a joint effort of end-user and vendor – is a written set of requirements that the finished parts must meet to be acceptable.

The various fabrication techniques for producing VESPEL® precision parts make possible great flexibility in meeting customer specifications.

The design engineer should always be aware that designing plastic parts usually requires higher tolerances than metal.

This manual presents typical property values for direct formed and machined parts. Since these published values are averaged, it is recommended not to base specifications on the maximum values.

Quality

VESPEL® parts are custom-made by DuPont to meet the stringent quality requirements of the world's most demanding original equipment manufacturers – part to part and order to order. Our Statitstical Process Control (SPC) procedure makes it possible to produce consistently high-quality parts at lower cost compared with conventional process control methods. The accuracy of SPC even permits some customers to eliminate their own inspection of incoming parts – for substantial cost savings.

Procedures include both laser inspection and computer video scanning for dimensional tolerances and uniformity, and ultrasonic testing for material integrity.

Because the production details of every order are kept on file, finished product can be traced all the way back to the original resin batch, if required.

All VESPEL® production sites are certified ISO 9001 and QS 9000.

As an example for our highest quality commitment the DuPont VESPEL® Mechelen site has received two Ford Q1 Awards, the Chrysler Penta Star and is rated as preferred supplier by Rolls Royce Aero Engines Company.

World wide, DuPont has implemented the total quality management system to ensure top quality under all aspects. For parts this means quality assurance from the incoming raw material to the finished part delivered in time to the customer.

DuPont's quality production follows the idea to avoid errors instead of eliminate tasks. We are committed to continuous improvement following the Ford Q1, the VDA (Verband der Automobilindustrie E.V.) guidelines as well as all the other quality requirements specified by our customers, using tools like

FMEA Failure mode error analysis;
SPC   Statistical process control;
RMI   Raw material inspection;
PITA   Production and inspection tool administration.

All items to ensure quality are listed in the quality handbook which is continuously updated.

Compositions and properties

VESPEL® precision parts are available in a number of standard and special purpose compositions. Some compositions contain fillers to enhance the performance of the polyimide material in one or two key characteristics.

Graphite is added, for example, to reduce friction and wear and TEFLON® fluoropolymer to lower static friction or reduce abrasion against soft metals. A brief description of DuPont's polyimide compositions follows.

Selector guide

VESPEL® SP for demanding applications

Grades	Typical End-Use Applications	Polyimide Compositions
SP1	Mechanical and electrical parts at elevated temperatures. Valve seats, seal, insulators.	Unfilled base resin. Maximum strength and elongation: lowest modulus and thermal conductivity: optimum electrical properties.
SP21	For lubricated or non-lubricated, low friction and wear applications. Valve seats, seals, bearings, washers, seal rings.	15% graphite (by weight). Enhances inherent wear resistance, improves long term thermal stability.
SP22	Applications in which low thermal expansion is more important than strength (which is slightly reduced). Bearings (bushings, washers, etc.).	40% graphite (by weight). Gives low coefficient of thermal expansion. Maximum creep resistance.
SP211	For low friction and wear applications in moderate temperature and PV environments. Bearings (bushings, washers, etc.).	15% graphite and 10% TEFLON® fluorocarbon resin (by weight). Lowest static friction.
SP3	For friction and wear applications in vacuum or inert gases. Bearings, piston rings and seals.	15% MoS2 (by weight). Best wear performance in dry environments.
SP221	For low wear applications in "non-lube" conditions against soft metals like aluminium, brass, bronze. Bearings (bushings, washers, etc.)	40% graphite (by weight) and 15% TEFLON® fluorocarbon resin. Lowest wear rate in dry service against soft metals.
SP262	Applications in which low thermal expansion and low coefficient of friction are more important than strength. Bushings.	57% graphite (by weight) and 5% carbon fibers. Lowest coefficient of thermal expansion and highest thermal conductivity.

VESPEL® ST meets tougher challenges – ST grades for highest toughness, strength and temperature

Grades	Typical End-Use Applications	Polyimide Compositions
ST2010	For lubricated or non-lubricated, low friction and wear applications. Valve seats, seals, bearings, washers, seal rings.	Excellent wear and friction properties combined with good toughness, strength and insulation properties. Contains 10% graphite. Highest elongation.
ST2030	Applications in which low thermal expansion is more important than strength (which is slightly reduced). Bearings (bushings, washers, etc.).	Lower coefficient of thermal expansion, lower elongation than ST2010. Contains 30% graphite. Highest oxidative and thermal stability.

We hope this publication stimulates ideas on how VESPEL® can help you solve your design challenges. If you have any questions, comments, or need additional information contact your local DuPont VESPEL® marketing representative before you begin your design. He will be happy to provide information on direct-formed parts, to discuss similar applications and to help you obtain VESPEL® materials for testing and prototyping.

Physical properties

VESPEL® precision parts, formed from DuPont polyimide resins, possess a unique combination of physical properties that add new dimensions to the plastic engineering materials currently available. These properties include an operating range from cryogenic temperatures to 500°C for many applications; continuous service temperature up to 300°C in air; very high PV (dry pressure velocity limits to 12 MPa · m/s, and even higher with lubrication), values for bearing applications; high dielectric strength; excellent mechanical strength and solvent resistance; low outgassing and high resistance to ionizing radiation. Summaries of typical properties are presented in Tables 1, 2, 3 and 4. The graphs and tables that follow provide specific details.

Table 1 Summary of typical properties standard SP polyimide resins

	Property	Temp. °C	ASTM Method	Units	SP1 M	SP1 DF	SP21 M	SP21 DF	SP22 M	SP22 DF	SP211 M	SP211 DF	SP3 M
MECHANICAL	Tensile strength, ultimate	23	D1708 or E8†	MPa	86,2	72,4	65,5	62,0	51,7	48,3	44,8	51,7	58,5
		260			41,4	36,5	37,9	30,3	23,4	26,2	24,1	24,1	
	Elongation, ultimate	23	D1708 or E8†	%	7,5	7,5	4,5	5,5	3,0	2,5	3,5	5,5	4,0
		260			6,0	7,0	3,0	5,2	2,0	2,0	3,0	5,3	–
	Flexural strength, ultimate	23	D790	MPa	110,3	82,7	110,3	82,7	89,6	62,1	68,9	68,9	75,8
		260			62,1	44,8	62,0	48,3	44,8	37,9	34,5	34,5	39,9
	Flexural modulus	23	D790	MPa	3102	2482	3792	3171	4826	4826	3102	2758	3275
		260			1724	1448	2551	1792	2758	2758	1379	1379	1862
	Compressive stress	23	D695	MPa									
	at 1 % strain				24,8	24,1*	29,0	22,8*	31,7	24,1	20,7	14,5*	34,5
	at 10 % strain				133,1	112,4*	133,1	104,8*	112,4	93,8*	102,0	75,8*	127,6
	at 0,1 % offset				51,0	33,1*	45,5	33,8*	41,4	25,5*	37,2	27,6*	
	Compressive modulus	23	D695	MPa	2413	2413*	2895	2275*	3275	2654*	2068	1379*	2413
	Axial fatigue, Endurance limit												
	at 10^3 cycles	23		MPa	55,8		46,2	–	–	–	–	–	–
		260			26,2		22,8	–	–	–	–	–	–
	at 10^7 cycles	23			42,1		32,4	–	–	–	–	–	–
		260			16,5		16,5	–	–	–	–	–	–
	Flexural fatigue, Endurance limit												
	at 10^3 cycles	23		MPa	65,5		65,5	–	–	–	–	–	–
	at 10^7 cycles	23			44,8		44,8	–	–	–	–	–	–
	Shear strength	23	D732	MPa	89,6		77,2						
	Impact strength, Izod, notched	23	D256	J/m	42,7		42,7						21,3
	Impact strength, Izod, unnotched	23	D256	J/m	747		320						112
	Poisson's ratio	23			0,41		0,41						
WEAR AND FRICTON	Wear rate ††			m/s×10^{-10}	17-85	17-85	6,3	6,3	4,2	4,2	4,9	4,9	17-23
	Coefficient of friction** PV = 0,875 MPa·m/s				0,29	0,29	0,24	0,24	0,30	0,30	0,12	0,12	0,25
	PV = 3,5 MPa·m/s				–	–	0,12	0,12	0,09	0,09	0,08	0,08	0,17
	In vacuum				–	–	–	–	–	–	–	–	0,03
	Static in air				0,35	–	0,30	–	0,27	–	0,20	–	–
THERMAL	Coefficient of linear thermal expansion	23 to 260	D696	µm/m/°C	54	50	49	41	38	27	54	41	52
		−62 to +23				45		34					
	Thermal conductivity	40		W/m · °C	0,35	0,29*	0,87	0,46*	1,73	0,89*	0,76	0,42*	0,47
	Specific heat			J/kg/°C	1130								
	Deformation under 14 MPa load	50	D621	%	0,14	0,20	0,10	0,17	0,08	0,14	0,13	0,29	0,12
	Deflection temperature at 2 MPa		D648	°C	~360		~360						

Table 2 Summary of typical properties standard SP polyimide resins

Property	Temp. °C	ASTM Method	Units	SP1 M	SP1 DF	SP21 M	SP21 DF	SP22 M	SP22 DF	SP211 M	SP211 DF	SP3 M
ELECTRICAL												
Dielectric constant	23	D150										
at 10^2 Hz				3,62	–	13,53	–	–	–	–	–	–
at 10^4 Hz				3,64	–	13,28	–	–	–	–	–	–
at 10^6 Hz				3,55	–	13,41	–	–	–	–	–	–
Dissipation factor	23	D150										
at 10^2 Hz				0,0018	–	0,0053	–	–	–	–	–	–
at 10^4 Hz				0,0036	–	0,0067	–	–	–	–	–	–
at 10^6 Hz				0,0034	–	0,0106	–	–	–	–	–	–
Dielectric strength short time 2 mm thick		D149	MV/m	22	–	9,84	–	–	–	–	–	–
Volume resistivity	23	D257	$\Omega \cdot m$	10^{14}-10^{15}	–	10^{12}-10^{13}	–	–	–	–	–	–
Surface resitivity	23	D257	Ω	10^{15}-10^{16}	–	–	–	–	–	–	–	–
OTHER PROPERTIES												
Water absorption		D570	%									
24 h	23			0,24	–	0,19	–	0,14	–	0,21	–	0,23
48 h	50			0,72	–	0,57	–	0,42	–	0,49	–	0,65
equilibrium, 50 % RH				1,0-1,3	1,0-1,3	0,8-1,1	0,8-1,1	–	–	–	–	–
Specific gravity		D792		1,43	1,34	1,51	1,42	1,65	1,56	1,55	1,46	1,60
Oxygen Index		D2863	%	53	–	49	–	–	–	–	–	–

†   Machined tensile specimens made per D1708 and direct-formed specimens made per figure 19 of E-8 (standard bar for powdered metallurgy products); specimens tested by D638.

*   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 0,875 MPa·m/s).

**   Steady state, unlubricated in air.

M: Parts machined out of shapes material.

DF: Parts obtained by «Direct Forming» process.

Table 3 Preliminary properties of new SP polyimide resins

	Property	Temp. °C	ASTM Method	Units	SP221	SP262
MECHANICAL	Tensile strength, ultimate	23	D638 (E8)	MPa	38,6	37,9
		260				19,3
	Strain at break	23	D638 (E8)	%	3,5	1
		260				0,7
	Flexural strength, ultimate	23	D790	MPa	55,1	
		260			31	
	Flexural modulus, ultimate	23	D790	MPa	3445	
		260			2205	
	Tensile modulus	23	D638 (E8)	MPa		8410
		260				3720
	Compressive stress		D695	MPa		
	Ultimate	23			111,7	100
	Ultimate	260			57	59
	at 1 % strain	23			14,5	40
	at 1 % strain	260			7,6	21,4
	at 10 % strain	23			78,6	
	at 10 % strain	260			46,5	
	Compressive modulus	23	D695	MPa	1412	2860
		260			790	1790
	Specific gravity		D732		1,6	1,74
WEAR AND FRICTION	PV limit			MPa·m/s	10,5	10,5
	Coefficient of friction					
	PV = 0,875 MPa·m/s					0,10-0,14
	PV = 3,5 MPa·m/s					0,05-0,08
	Wear factor					
	PV = 0,875 MPa·m/s			mm^3/Nm × 10^{-6}		0,44
	PV = 3,5 MPa·m/s					0,66
	Wear and friction against 6061 Wrought Aluminium					
	PV = 0,875 MPa·m/s Coefficient of friction				0,21	
	PV = 0,875 MPa·m/s Wear rate Vespel® / Metal			mm/s 10^{-6}	2,3 / 0	
	Wear and friction against ADC 12 Diecast Aluminium					
	PV = 0,5 MPa·m/s Coefficient of friction				0,15	
	PV = 0,5 MPa·m/s Wear rate Vespel® / Metal			mm/s 10^{-6}	1,2 / 0	
	PV = 4,7 MPa·m/s Coefficient of friction				0,12	
	PV = 4,7 MPa·m/s Wear rate Vespel® / Metal			mm/s 10^{-6}	3,7 / 0,3	
THERMAL	Coefficient of linear thermal expansion		D696	μm/m·°C		
	Perpendicular	23-300			29	13,1
	Parallel	23-300				48,9
	Thermal conductivity	23		W/m·K		2,46
		200				1,98
	Specific heat	23		J/kg·K		792
		40				837

Table 4   Typical properties of Direct-Formed VESPEL® ST parts

	Property	Temp. °C	ASTM Method	Units	ST2010	ST2030
MECHANICAL	Tensile strength	23 150 260 300	D638	MPa	68 49 32 26	57
	Strain at break	23 150 260 300	D638	%	10,0 10,0 9,8 9,7	4,9
	Tensile modulus	23	D638	MPa	2758	3930
	Izod notched impact strength	23	D256	J/m	53	
	Compressive strength 1 % strain 10 % strain ultimate	23	D695	MPa	15 82 269	155
	Compressive modulus	23	D695	MPa	1827	1207
ELECTRICAL	Dielectric strength	23	D149	kV/mm	10,4	
	Dielectric constant 100 Hz 10 kHz 1 MHz	23	D150		4,80 4,78 4,70	300 110 40,6
	Dissipation factor 100 Hz 10 kHz 1 MHz	23	D150		0,0014 0,0023 0,0075	6,90 0,65 0,30
	Volume resistivity	23	D257	ohm·cm	$3,2 \times 10^{16}$	$4,8 \times 10^{7}$
	Surface resistivity	23	D257	ohm	$2,0 \times 10^{16}$	$2,6 \times 10^{6}$
MISCELLANEOUS	Thermal conductivity	23	F433	$[W \cdot cm/cm^2 \cdot °C] \times 10^{-3}$	5,0	9,7
	Coefficient of linear thermal expansion	23-260	D696	µ/m/°C	48	32
	Water absorption % change (weight), 24 h 48 h	23	D570		1,3 3,1	0,5 1,3
	Deformation under 14 MPa load	23 50	D621	%	0,18 0,38	
	Specific gravity	23	D272		1,38	1,44

Note: ST Stock Shapes are not yet available.

Effect of temperature

Since SP and ST polyimides do not melt and have 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 2 through 5 illustrate typical changes in tensile strength and modulus of elasticity with temperature for machined and direct-formed parts.

The upper use temperature of SP and ST polyimides is limited by their rate of degradation, not by a softening point where they would lose their load-carrying capability. Parts may be used continuously in air up to 300°C and for short excursions to as high as 500°C.
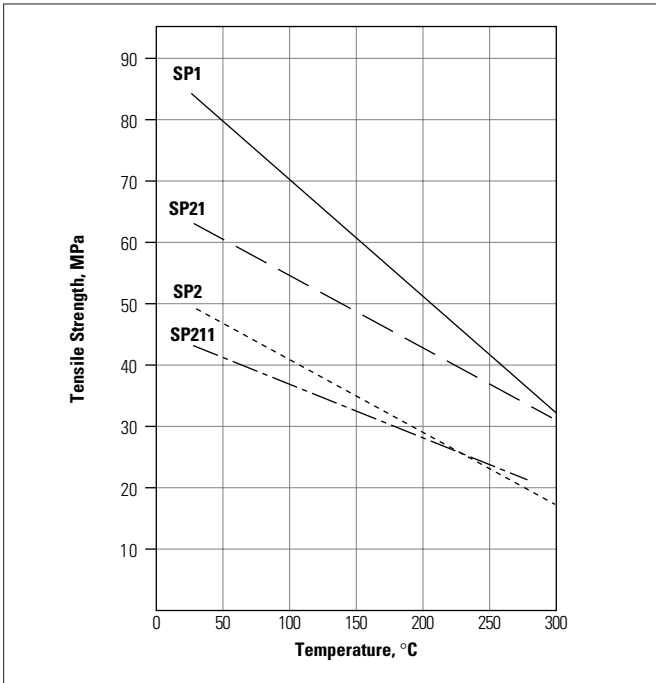

Fig. 2 **SP polyimide shapes. Typical ultimate tensile strength vs. temperature, ASTM D1708**
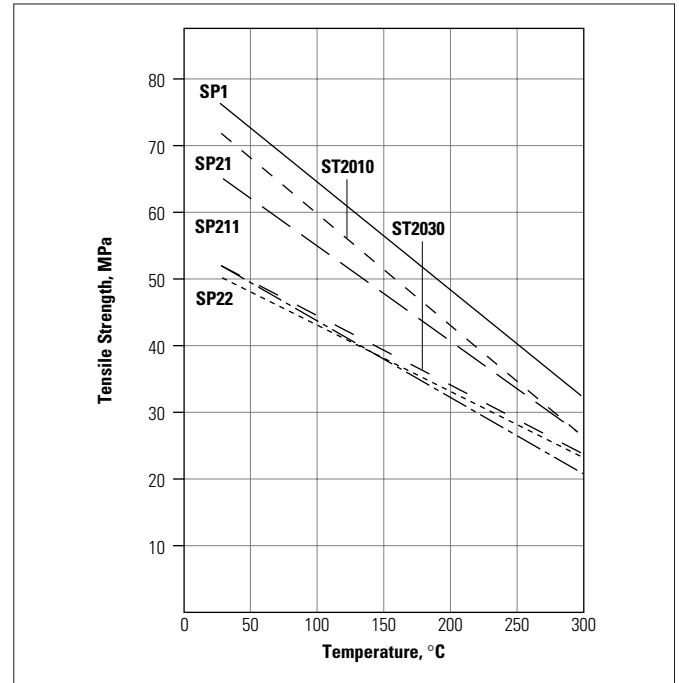

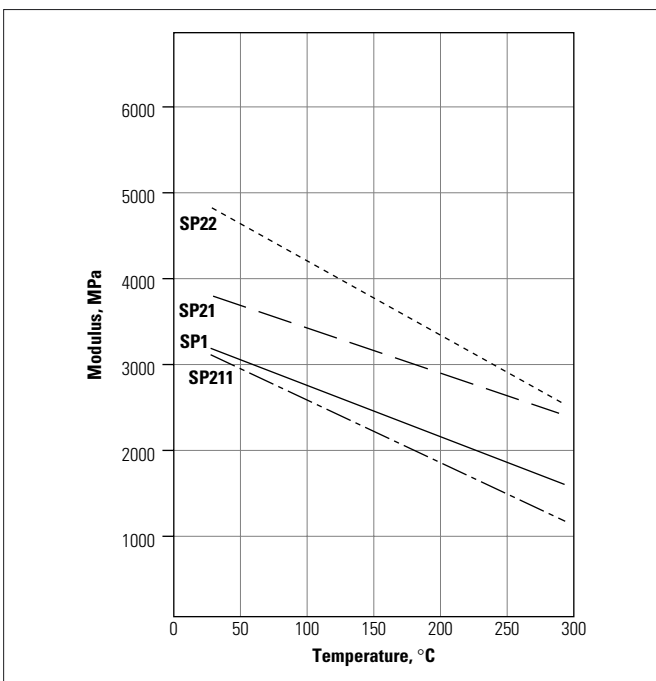Fig. 3 **Direct formed SP and ST polyimide. Typical ultimate tensile strength vs. temperature, ASTM E8**

Fig. 4 **SP polyimide shapes. Typical modulus of elasticity (flexural modulus) vs. temperature, ASTM D740**
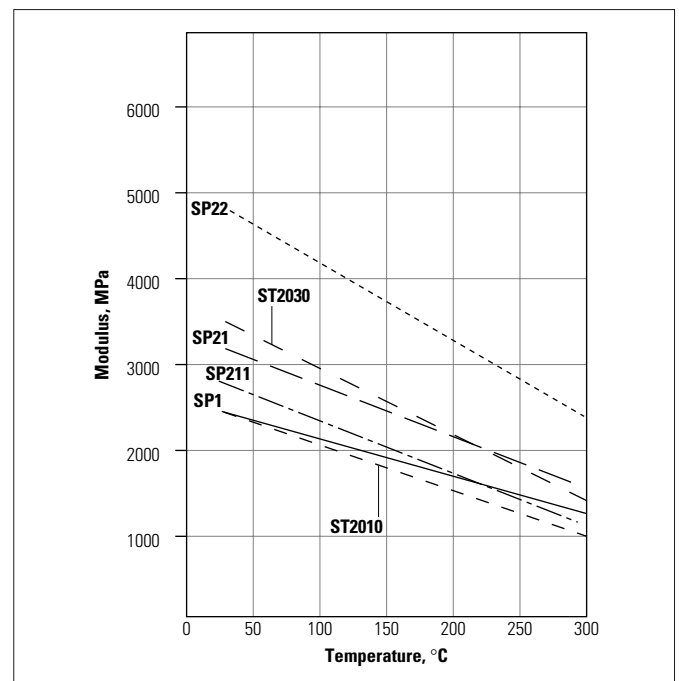

Fig. 5 **Direct formed SP and ST polyimide. Typical modulus of elasticity (flexural modulus) vs. temperature, ASTM D790**
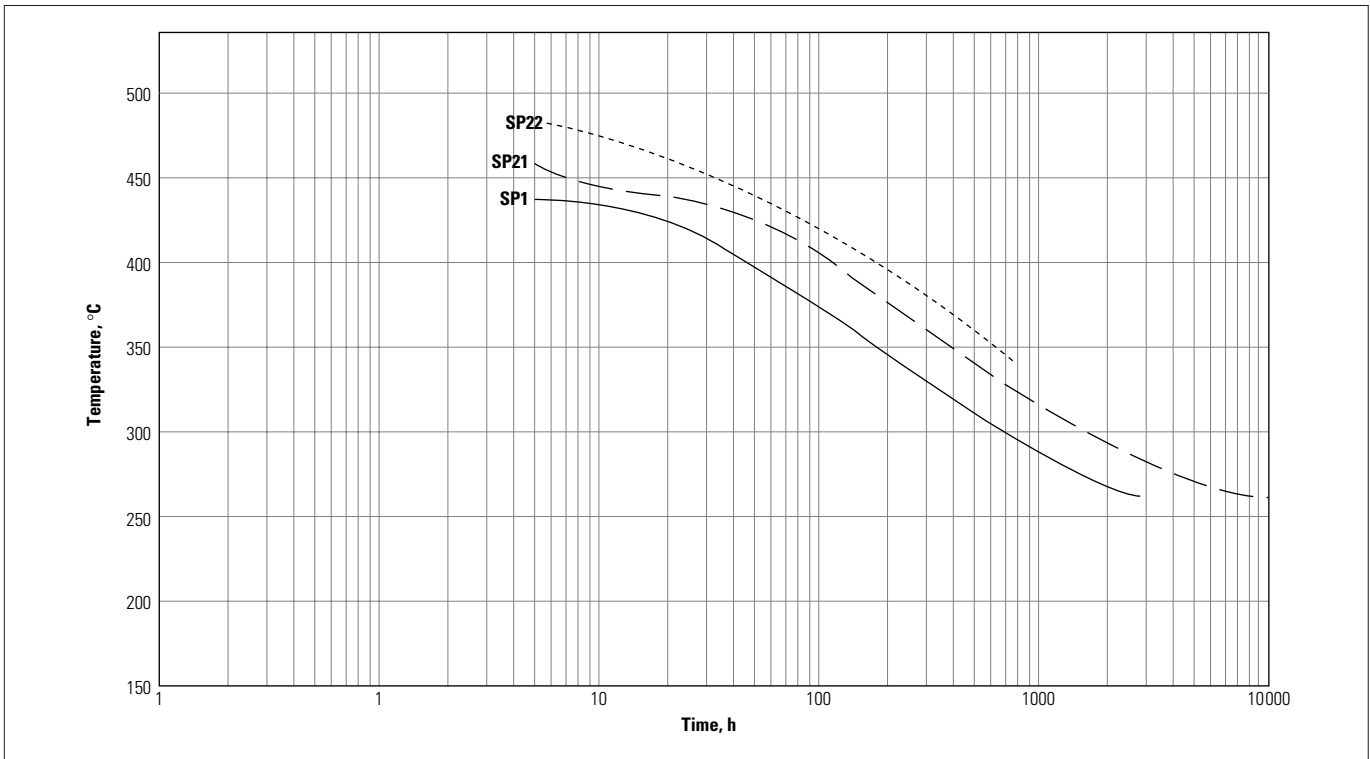
11

Fig. 6 **SP polyimide exposure to air at elevated temperature. Approximate time to 50% reduction in tensile strength vs. temperature**

Figure 6 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 370°C, SP1 polyimide will retain half its initial strength. The graphite filler in SP21 and SP22 polyimide imparts some physical stability to the parts which is manifested in a greater retention of properties with time. SP21 (15% graphite) requires about 200 hours at 370°C and SP22 (40% graphite) 350 hours to reach the 50% strength level.

The loss in properties with time at temperatures up to about 400°C is due almost entirely to oxidative degradation. At temperatures up to at least 340°C, SP parts will perform in inert environments such as nitrogen or vacuum with negligible loss of properties with time.

Naturally, the data in the Figure 6 should only be used as a guide, since the useful service life of VESPEL® parts is usually much greater. This is because the temperatures encountered are often intermittent instead of continuous, and because the parts are generally covered to some extent by a housing or retainer. Seldom are VESPEL® parts totally exposed to air in high-temperature applications.

Super tough ST

- **Higher Temperature Capabilities**
  Because VESPEL® ST parts have such good initial mechanical properties, they retain functional levels of toughness and strength for longer periods at elevated temperatures than SP.
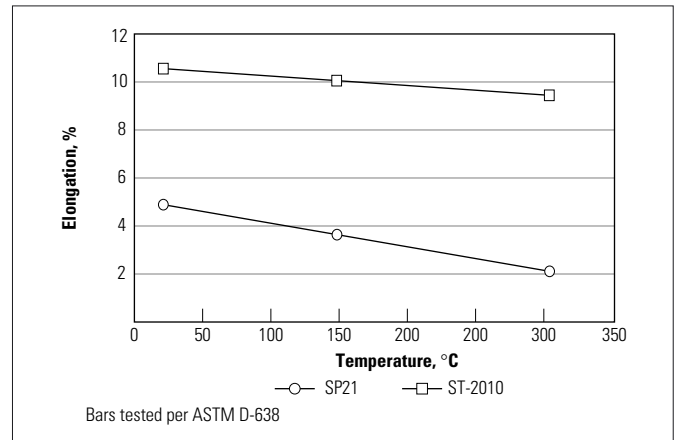

Fig. 7 **Ultimate elongation vs. temperature SP21 vs. ST2010**

- **Superior toughness**
  VESPEL® ST parts have about double the elongation of earlier SP polyimides (Fig. 7). Impact strength (notched Izod) is about 50% higher (see Table 4).

- **Higher strength**
  VESPEL® ST components are stronger than comparable SP parts both in tension and ultimate compression, as shown in Figures 8 and 9.

Stress-strain curves

Figures 10 and 11 show typical stress-strain curves in tension for machined SP polyimide parts at 23°C and 260°C; Figures 12 and 13 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.
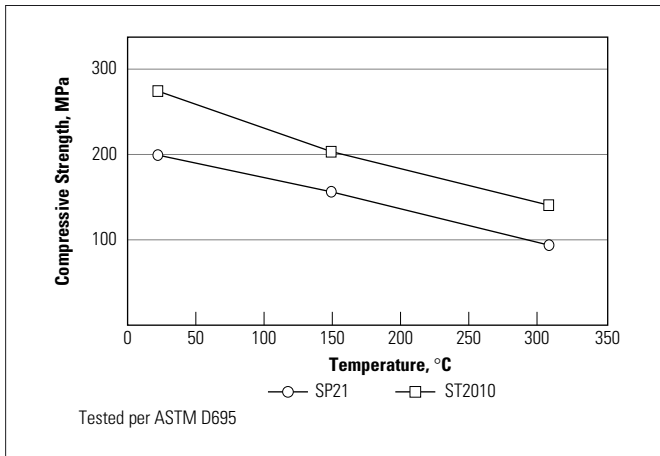
12

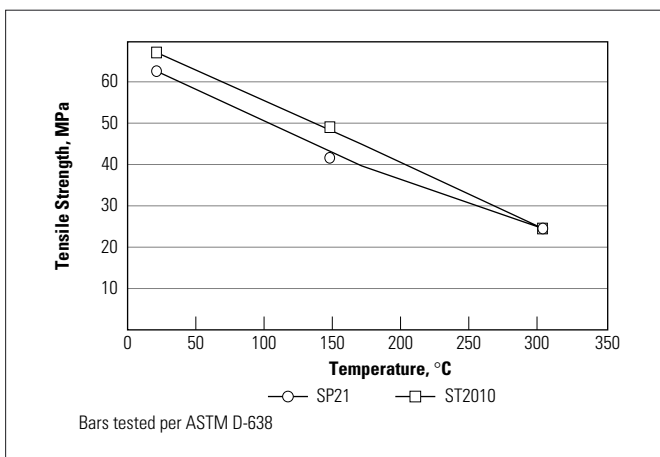Fig. 8 **Ultimate compressive strength vs. temperature SP21 vs. ST2010**

Fig. 9 **Ultimate tensile strength vs. temperature SP21 vs. ST2010**
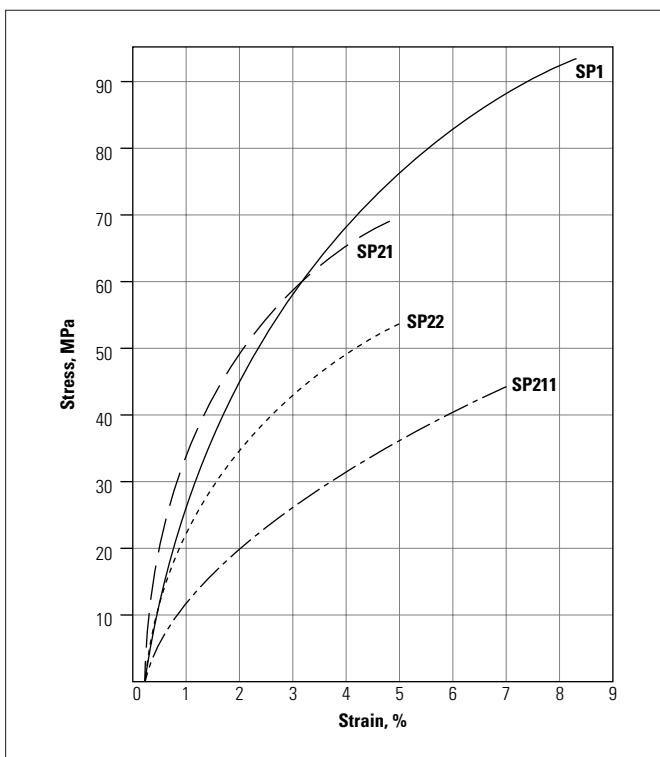
Fig. 10 **SP polyimide shapes. Typical stress-strain in tension at 23°C, ASTM D1708**
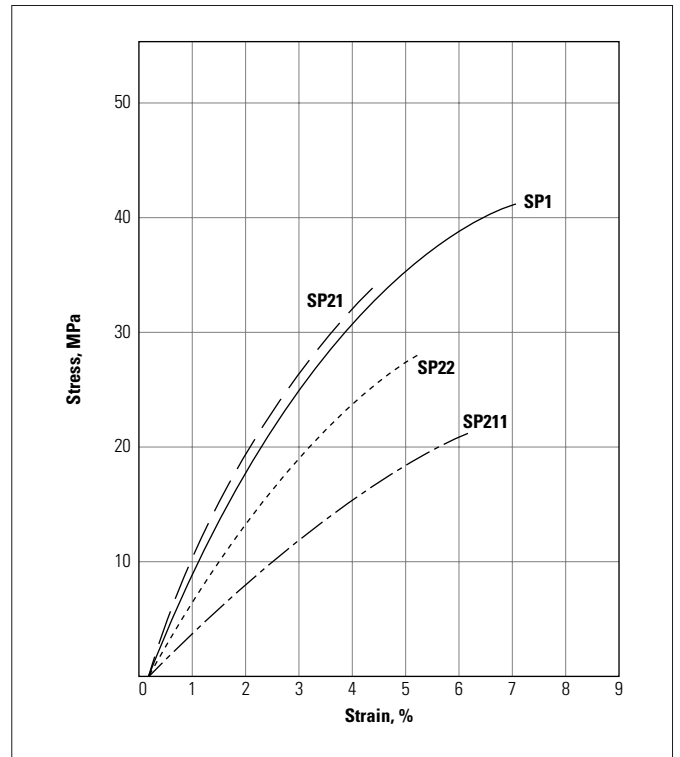
Fig. 11 **SP polyimide shapes. Typical stress-strain in tension at 260°C, ASTM D1708**

Fig. 12 **Direct formed SP polyimide. Typical stress-strain in tension at 23°C, ASTM E8 (⊥ to forming)**

Figures 14 through 16 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

13
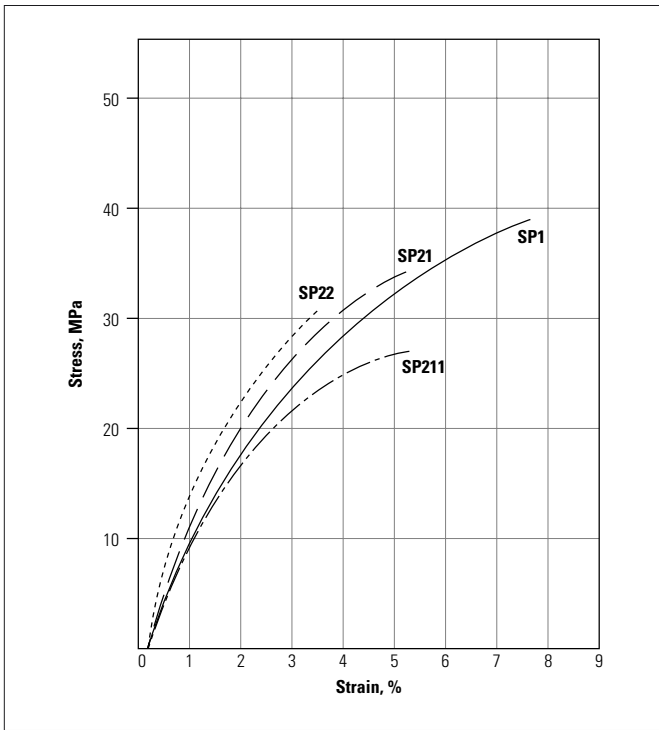
Fig. 13 **Direct-formed SP polyimide. Typical stress-strain in tension at 260°C, ASTM E8 (⊥ to forming)**

Fig. 15 **SP polyimide shapes in compression at 300°C, ASTM D695**

limits of loading without significantly exceeding the elastic limits of the materials. Table 1 also provides the SP compressive stress data calculated for 0,1% permanent deformation in the part. Unlike thermosetting materials, polyimides can be compressed several per cent before reaching this deformation level. The materials are quite compliant and useful in forming seals of many types.
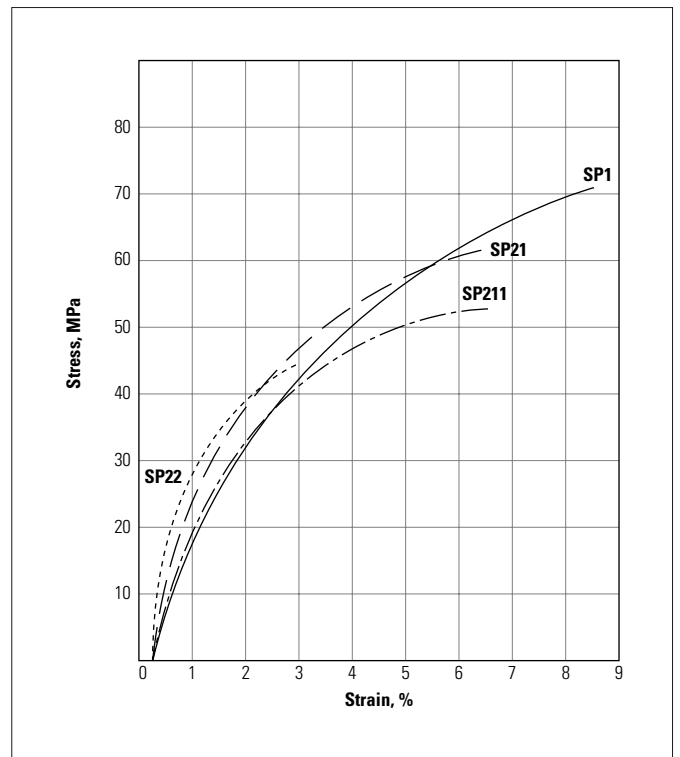

Fig. 14 **SP polyimide shapes in compression at 23°C, ASTM D695**

Fig. 16 **Direct-formed SP and ST polyimide. Typical stress-strain in compression at 23°C, ASTM D695 (∥ to forming)**

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-dependant decrease in the stress needed to maintain a constant strain is called stress relaxation.

Figures 17, 18 and 19 show total deformation or strain vs. time under 10,3 and 17,2 MPa for machined SP1, SP21 and SP22 polyimide at two temperatures.
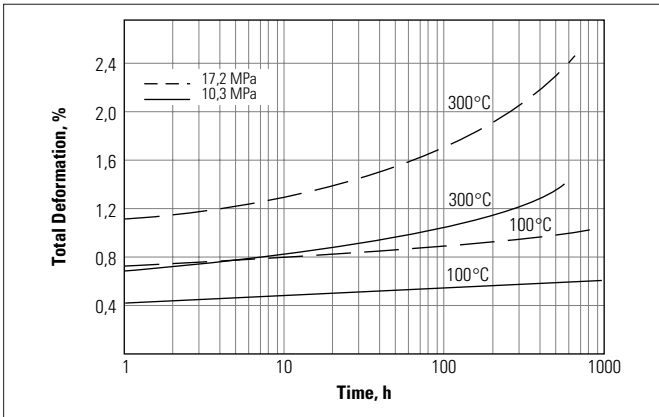
Fig. 17   **SP1 polyimide shapes. Total deformation under load vs. time**
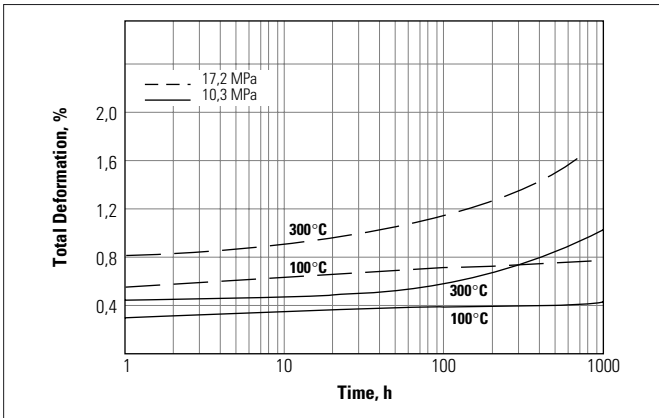
Fig. 18   **SP21 polyimide shapes. Total deformation under load vs. time**
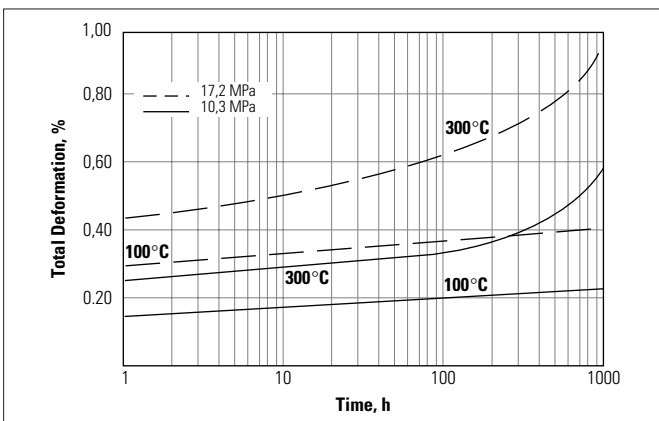
Fig. 19   **SP22 polyimide shapes. Total deformation under load vs. time**

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, SP21 and SP22. For example, Figure 19 shows that creep for SP22 polyimide at 17,2 MPa and 300°C is only 0,5% after 1000 hours.

Figures 20 through 22 give the change in apparent modulus of elasticity with time corresponding to Figures 17 through 19. 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.
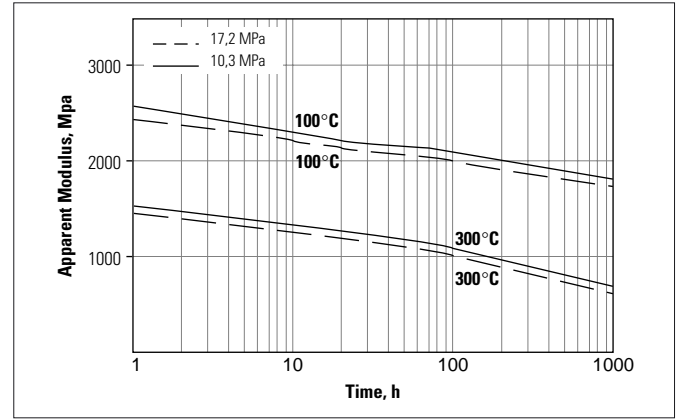
Fig. 20   **SP1 polyimide shapes. Apparent modulus vs. time under load**
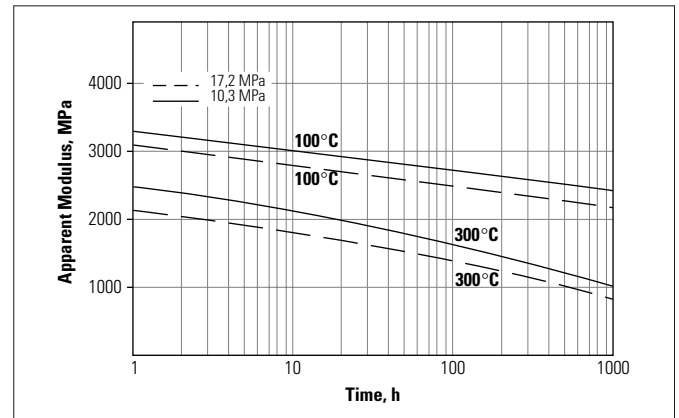
Fig. 21   **SP21 polyimide shapes. Apparent modulus vs. time under load**
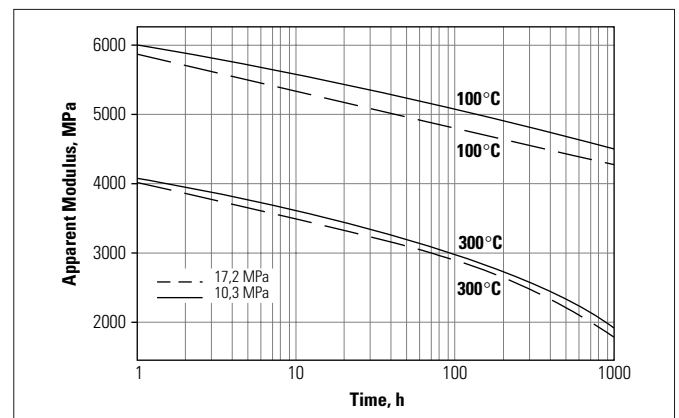
Fig. 22   **SP22 polyimide shapes. Apparent modulus vs. time under load**

15

Effect of moisture absorption

Figures 23 through 25 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.
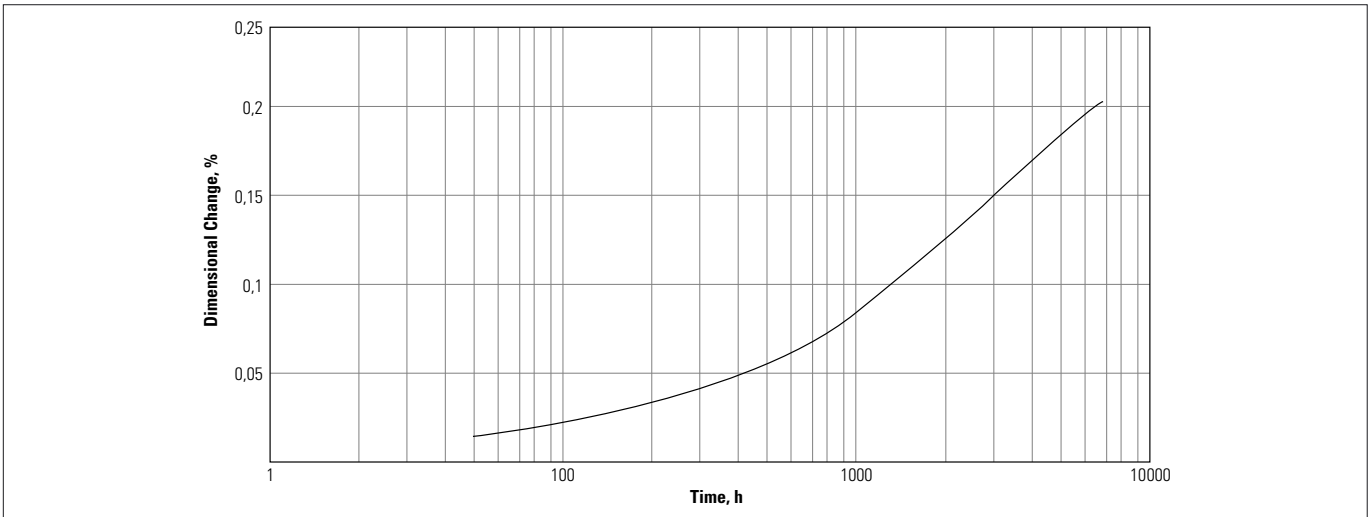
Fig. 23 **SP1 and SP21 polyimide shapes. Typical dimensional change vs. time at 23°C, 50% RH, 3,2 mm plaques**
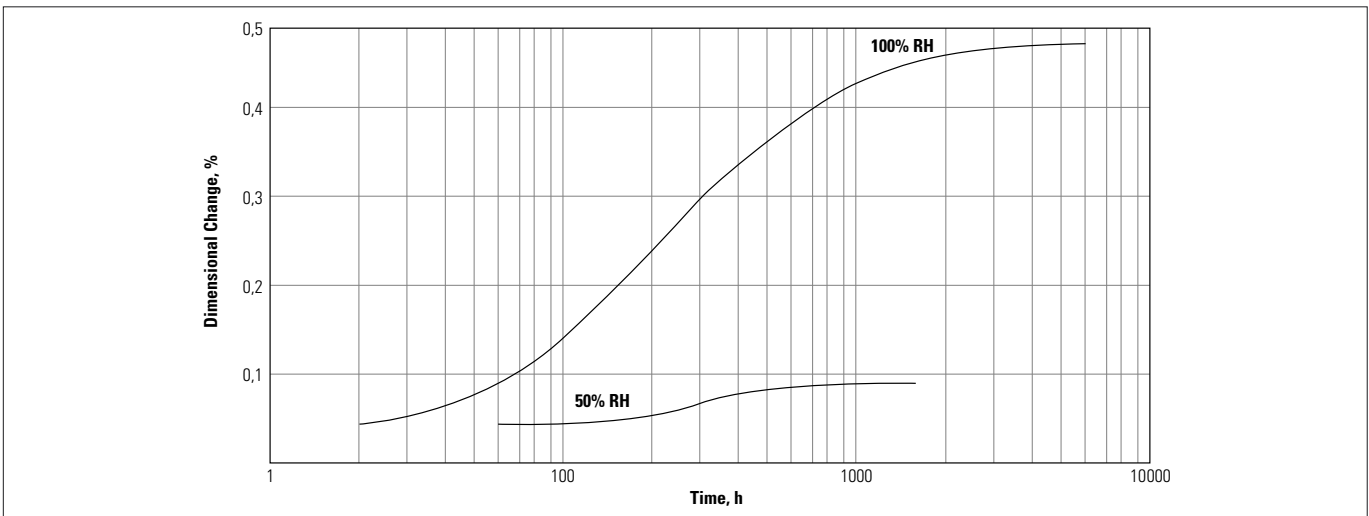
Fig. 24 **Direct-formed SP1 polyimide. Typical dimensional change with time at 50 and 100% RH, 23°C, 25 mm dia. discs, 2,5 mm thick**
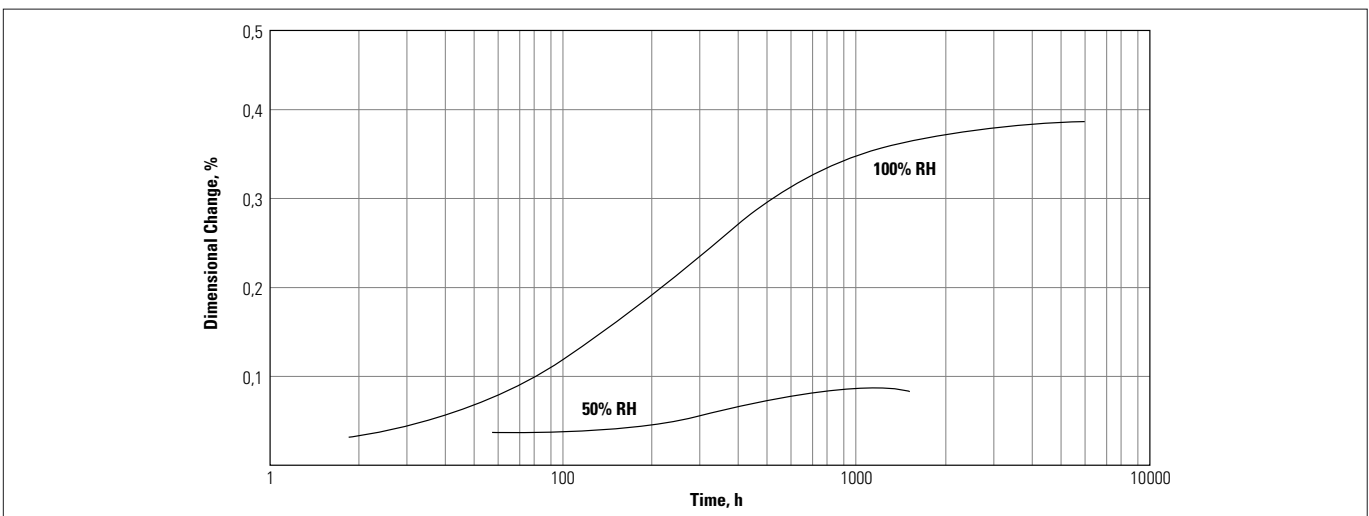
Fig. 25   **Direct-formed SP21 polyimide. Typical dimensional change with time at 50 and 100% RH, 23°C, 25 mm dia. discs, 2,5 mm thick**

16

Figures 26 and 27 show typical effects of relative humidity (RH) changes at 23°C 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 23°C will result in a maximum change of about 0,5% or 0,005 mm/mm.
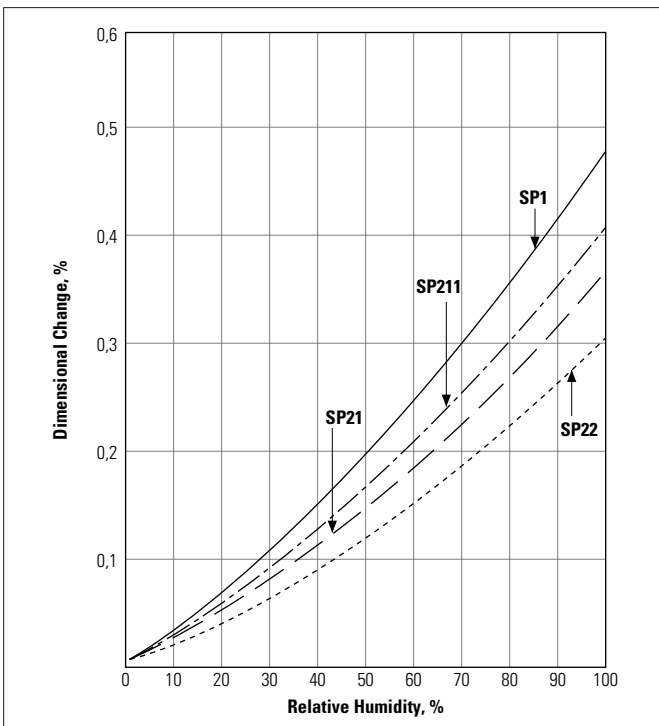
Thermal expansion

Linear dimensional change with temperature is shown in Figure 28 for machined SP polyimide and in Figure 29 for direct-formed polyimide. Each plot contains the average coefficient of thermal expansion over the temperature range 23°C to 300°C. The coefficient over any other range of temperature may be slightly different and can be determined from the curves by dividing the per cent dimensional change over the desired range by $100 \times$ the temperature differential in degrees (ΔT).

Fig. 26 **SP1 anf SP21 polyimide shapes. Typical dimensional change with relative humidity at equilibrium, 23°C**
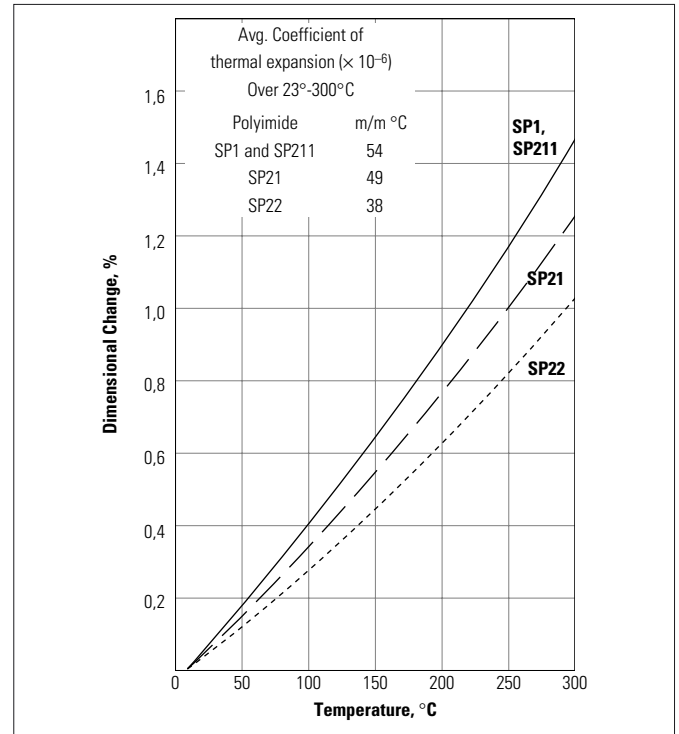
Fig. 28 **SP polyimide shapes. Linear thermal expansion ASTM D696**

Fig. 27 **Direct-formed SP polyimide. Typical dimensional change with relative humidity at equilibrium, 23°C**
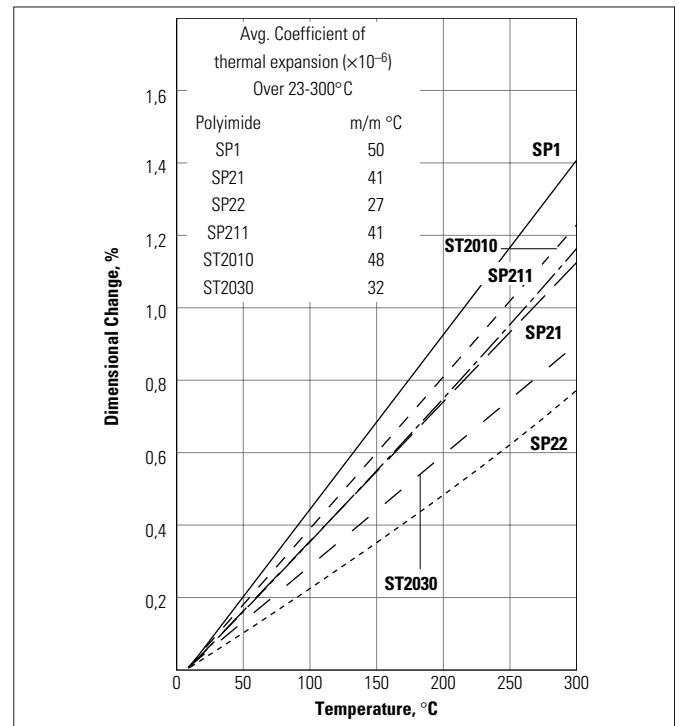
Fig. 29 **Direct-formed SP and ST polyimide. Linear expansion ($\perp$ to forming) ASTM D696**

17

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, SP21 and SP22 polyimide offer a lower expansion than unfilled SP1. The coefficient of thermal expansion of SP22 approaches that of aluminium and the one of SP262 steel.

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 260 °C is shown in Figure 30 for machined SP1 and SP21. 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 testing 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.

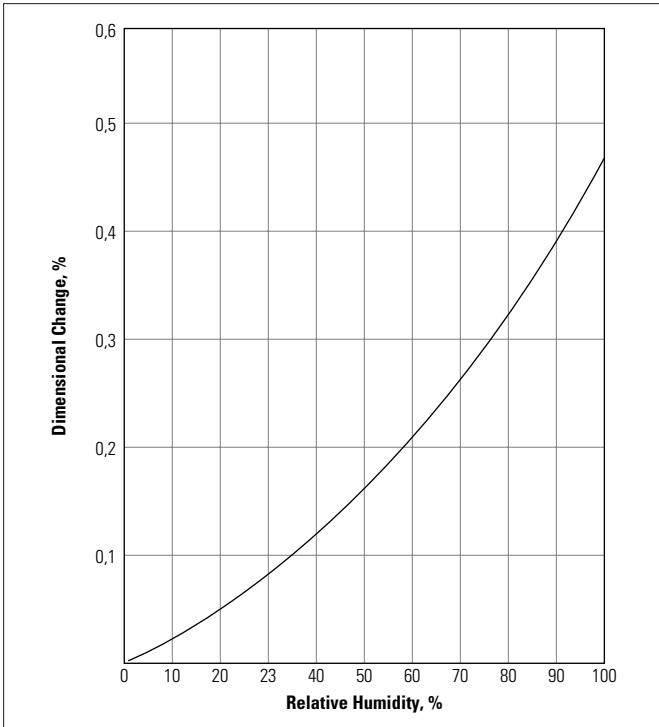SP and ST polyimides, like most other plastics, displays notch sensitivity as shown by the values of notched Izod impact strength shown in Tables 1 and 4. As with most materials, avoid designing sharp corners and other stress raisers into the part.

Electrical properties

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

The dielectric constant (Fig. 31) decreases gradually from 3,5 at room temperature to 3,0 at 260°C. At a given temperature, dielectric constant is essentially
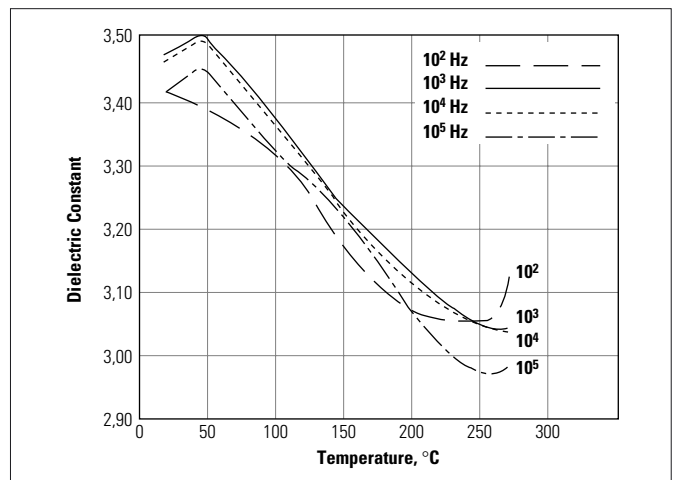
Fig. 31 **Dielectric constant vs. temperature (SP1) ASTM D150**

Fig. 30 **SP polyimide shapes. Typical fatigue resistance vs. temperature reversed tensile and compressive stress, 1800 cycles/min (30 Hz)**
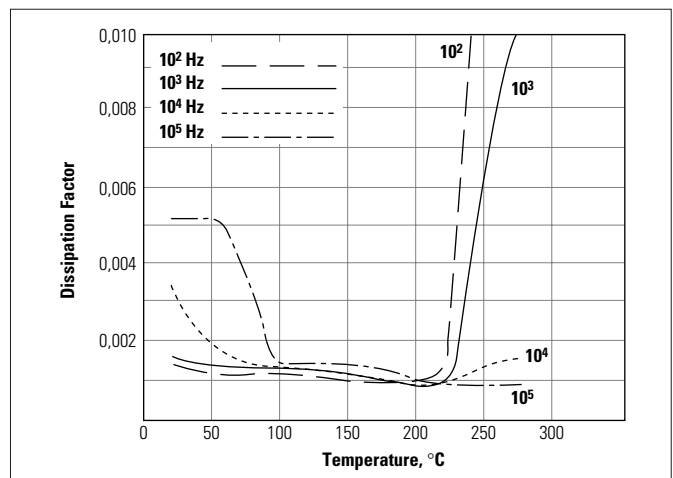
Fig. 32 **Dissipation factor vs. temperature (SP1) ASTM D150**

unchanged with frequency variations in the range of 10^2 to 10^5 Hz. Dissipation factor (Fig. 32) is influenced by both temperature and frequency. Up to about 100°C, dissipation factor increases with increasing frequency. From 100 to 200°C, frequency has essentially no effect, while above 200°C, dissipation factor decreases with increasing frequency.

Both dielectric constant and dissipation factor increase with increasing moisture content. For example, at 10^3 Hz and room temperature, the dielectric constant of a dry test bar (fabricated from SP1 polyimide resin) is 3,1 and the dissipation factor is 0,001. With a moisture content of 2,4% (obtained after 300 hours immersion in water at room temperature), these values are 4,0 and 0,002, respectively. Drying will restore the original values.
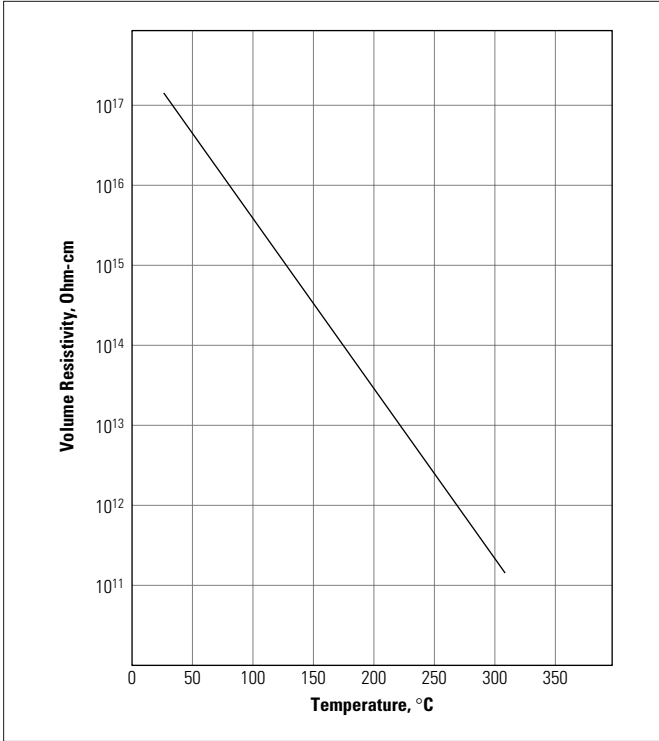
Fig. 33 **SP1 polyimide shapes. Volume resistivity vs. temperature, ASTM D257**
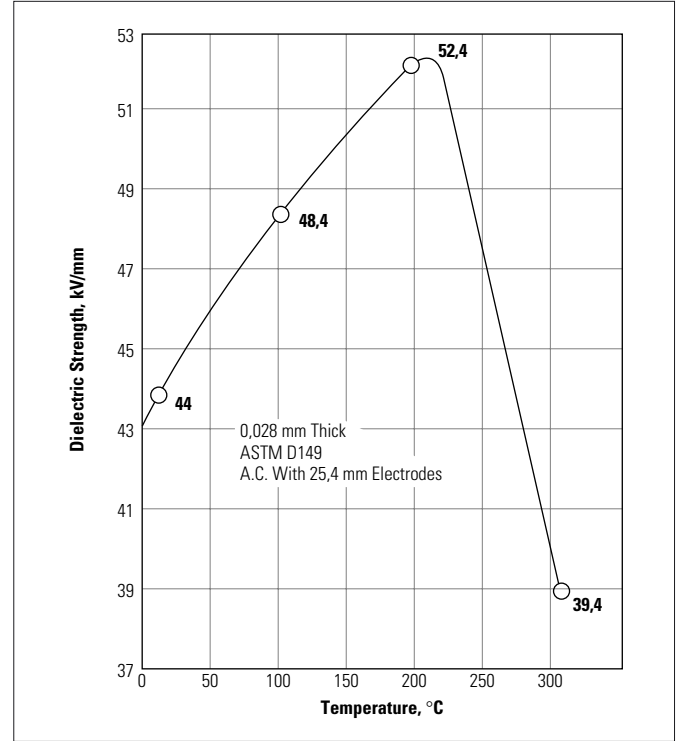
Fig. 35 **SP1 polyimide shapes. Dielectric strength vs. temperature in air, ASTM D149**
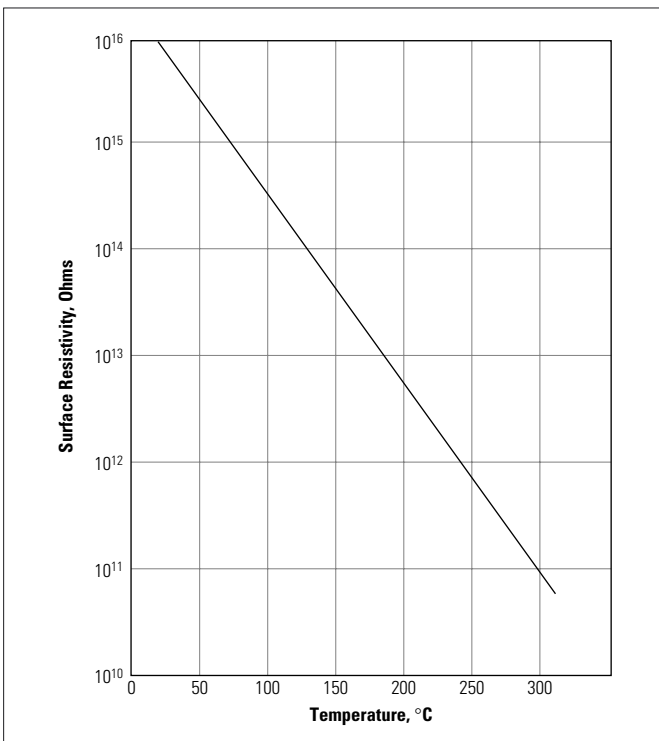
Fig. 34 **SP1 polyimide shapes. Surface resistivity vs. temperature, ASTM D257**
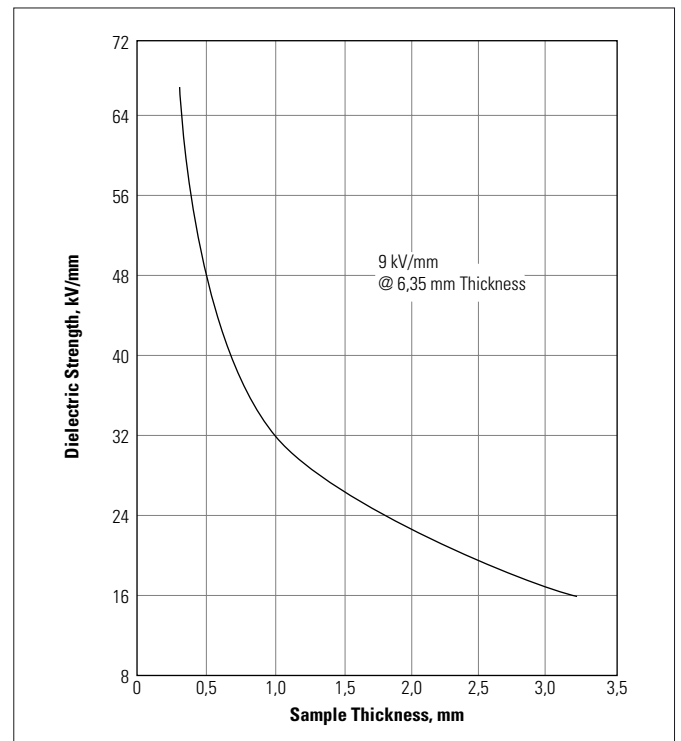
Fig. 36 **SP1 polyimide shapes. Dielectric strength vs. thickness, ASTM 149 – IN A-8 oil**

19

Moisture content has relatively little effect on volume and surface resistivities.

The volume resistivity of samples moulded from unfilled polyimide is 10^{17} ohm-cm at room temperature (Fig. 33). This value decreases linearly to 10^{11} ohm-cm at 300°C. Surface resistivity (Fig. 34) is 10^{16} ohm at room temperature, and decreases linearly to 5×10^{10} at 300°C.

The corona resistance of VESPEL® parts is superior to that attainable with fluorocarbons and polyethylenes. For example, at 7,8 kV/mm (60 Hz and room temperature), corona life is 2200 hours.

Effect of chemicals

VESPEL® SP parts perform well in a variety of chemical environments. The tensile strength data shown in Table 5 were determined using exposure tests patterned after ASTM Method D 543-67, "Resistance of plastics to chemical reagents".

Improved chemical resistance

VESPEL® ST parts also exhibit improved chemical resistance (especially to acids and bases) and better hydrolytic stability while retaining the outstanding solvent resistance of SP parts.

A. Solvents

1. Organic solvents in general have little effect on the mechanical and dimensional stability of polyimide parts.

2. Chlorinated and fluorinated solvents such as perchlorethylene, trichlorethylene and Axarel® are recommended for surface cleaning of VESPEL® parts.

3. Hydrocarbon solvents such as toluene and kerosene have virtually no effect on the polyimide material.

4. At high temperatures some solvents containing functional groups such as m-cresol and nitrobenzene can cause swelling of SP without substantially reducing its mechanical strength.

5. Below are some solvents which have been tested:

perchlorethylene	1900 hours at 100°C. 100% retention tensile strength 0,4% wt. loss
toluene	1900 hours at 100°C. 85% retention tensile strength 0,1% wt. loss
ethanol	1900 hours at 100°C. 100% retention tensile strength 0,2% wt. gain
diethyl ketone	1900 hours at 100°C. 75% retention tensile strength 0,3% wt. gain

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* Axarel is a registered trademark of E.I. du Pont de Nemours and Company for fluorocarbon products.

JP-4 jet fuel	1900 hours at 100°C. 80% retention tensile strength 0,8% wt. loss
o-dichlorobenzene	1000 hours at 180 °C. 100% retention tensile strength 2,4% wt. gain
m-cresol	1000 hours at 200 °C. 75% retention tensile strength 3% dimensional increase
nitrobenzene	1000 hours at 215 °C. 85% retention tensile strength 9% wt. gain 2,5% dimensional increase

B. Oils

1. **Jet engine oils:** Exposures of SP1 and SP21 in a MIL L7808 oil and a type 2 jet oil were made at 260°C. In both oils SP1 retained 60% of its tensile strength and 30% of its elongation after 600 hours, while SP21 retained 90% and 70% of the same properties, respectively. After 1000 hours the retention of tensile strength was 30% for SP1 and 60% for SP21. Retention of elongation was 10% for SP1 and 30% for SP21. Both compositions gained about 0,2% weight in the MIL L7808 oil and 0,5% in the type 2 oil in 1000 hours. Dimensions in the parallel direction increased up to 0,3% while those in the perpendicular direction decreased up to 0,1%.

2. **Silicone fluid:** At 260°C, SP1 retained 70% of its tensile strength and 35% of its elongation after 1000 hours. SP21 retained 85% of its tensile strength and 50% of its elongation under the same conditions. Both compositions gained 0,3% in weight. Dimensional increases in the parallel direction were 0,2% while decreases in the perpendicular direction were less than 0,1%.

3. **Refined mineral oil:** At 200°C retention of tensile strength after 1000 hours was 70% for SP1 and 90% for SP21. Retention of elongation was 40% for SP1 and 65% for SP21. Weight gains were about 0,3%. Dimensional increases were about 0,1% in the parallel direction while decreases in the perpendicular direction were less than 0,1%.

4. **Polyphosphate ester hydraulic fluid:** No changes in properties were noted after 1000 hours at 120°C.

5. **Tricresyl phosphate (oil additive):** After 1000 hours at 260°C, SP1 gained 1,5% in weight retaining 80% of its tensile strength. Dimensions increased about 0,25%.

C. Water

1. At 100°C the tensile strength and elongation of SP are reduced to 45% and 30% of the original values respectively, in about 500 hours, at which point they level out.

2. Most of the reduced tensile values from 100°C water exposure can be restored by drying, indicating that the reduced properties are not due to chemical changes.

3. VESPEL® parts can be used in applications where they are exposed to water up to 100°C, providing the stresses are low enough to take into account the reduced mechanical properties.

4. As with all polyimides, SP is subject to hydrolysis. Severe cracking may occur in water or steam at temperatures exceeding 100°C.

D. Acids

1. Concentrated mineral acids cause severe embrittlement of polyimide parts in a relatively short time.

2. Concentrated (38%) hydrochloric acid caused a 30% reduction in tensile strength and a 40% reduction in elongation after 120 hours exposure at room temperature.

3. Concentrated (70%) nitric acid caused a 60% reduction in tensile strength and a 75% reduction in elongation after 120 hours exposure at room temperature. These large decreases are probably due, in part, to the oxidizing action of the acid.

4. Five per cent (5%) hydrochloric acid reduced the tensile strength of SP by 80% after 1900 hours at 100°C.

5. Fifteen per cent (15%) acetic acid reduced the tensile strength of SP by 80% after 1900 hours at 100°C.

6. Generally, dilute acid solutions and aqueous solutions of inorganic salts having acidic pH's have about the same effect on SP as does water itself.

E. Bases

1. Generally, polyimide resins are susceptible to alkaline attack. Aqueous bases attack VESPEL® parts chemically, causing rapid deterioration of properties.

2. A 5% solution of sodium hydroxide reduced the tensile strength of SP by 45% upon exposure for 120 hours at room temperature. The normally brown colour of the SP surfaces became black and the weight increased by 27%.

3. All basic solutions with a pH of 10 or greater, including salt solutions, should be avoided.

4. Cleaning agents of a caustic nature are not recommended.

5. Non-aqueous bases such as anhydrous ammonia (liquid or vapour) and the hydrazines readily attack SP chemically.

6. Severe cracking occured when SP was exposed to liquid anhydrous ammonia for a relatively short period of time.

7. Blistering and other evidence of chemical attack occurred upon exposure to ammonia vapour.

8. Both liquid and gaseous unsym.-dimethyl hydrazine caused a 55% reduction in tensile strength and a 35% reduction in elongation in a short period of time.

9. Primary and secondary amines can attack SP chemically.

10. All chemicals basic in nature should be avoided in applications of polyimide parts.

Table 5   Effects of chemicals

Chemical media	°C	Time, hours	% tensile strength retained by SP1
Organic solvents			
M-Cresol	200	1000	75[1]
o-Dichlorobenzene	180	1000	100
Diethyl ketone	100	1900	100
Ethanol	100	1900	100
Nitrobenzene	215	1000	85[1]
Perchloroethylene	100	1900	100
Toluene	100	1900	85
Industrial fluids			
Hydraulic fluid ("Skydrol") Polyphosphate ester	120	1000	100
JP-4 Jet fuel	100	1900	80
Jet engine oils (MIL L 7808G)	260 260	600 1000	60 (90)[2] 30 (60)[2]
Mineral oil	200	1000	70 (90)[2]
Silicone fluid	260	1000	80
Tricresyl phosphate (oil additive)	260	1000	80
Acids			
Acetic, 15%	100	1900	20
Hydrochloric, 38%	23	120	70
Hydrochloric, 5%	100	1900	15
Nitric, 70%	23	120	40
Bases			
Sodium hydroxide, 5%	23	120	55
Oxidizing agents			
Nitrogen tetroxide	23	120	60

1 Swelling.
2 SP21 polyimide (15% graphite-filled).

F. Oxidizing agents

1. Chemical reagents which act as powerful oxidizing agents can cause oxidation of VESPEL® parts even under mild conditions. (See acids for the effect of nitric acid.)

2. Nitrogen tetroxide (N_2O_4) caused a 40% reduction in both tensile strength and elongation after 120 hours at room temperature. A three per cent weight gain also occurred.

G. Oxygen compatibility

An important property of SP21 is its compatibility with liquid and gaseous oxygen systems.

DuPont's SP21 has been tested by the National Aeronautics and Space Administration and meets MSFC-SPEC-106B, "Testing Compatibility of Materials for Liquid Oxygen Systems". At present time this approval is on a selected-lot basis.

Similarly, SP21 was tested by the Naval Air Engineering Center, Department of the Navy, and was found compatible according to MIL-V-5027C, "Non-Metallic Materials Compatible with Oxygen".

Tested by other laboratories, it has been found that ST2010 is also compatible with oxygen as SP21.

It is likely that other filled SP compositions will meet the above specifications but have not been tested. The unfilled resin – SP1 – does not meet these standards.

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.

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 inconfined 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 93°C gave a weight loss rate of less than 10^{-10} g/cm^2/s at temperatures below 260°C. At 350°C the weight loss rate was 10^{-7} g/cm^2/s.

Flammability classification, UL 94

VESPEL® is classified UL 94-5V and 94 V-0. It covers SP1, SP21, SP22 and SP211 for a minimum thickness between 1,6 and 1,7 mm. ST products have not been evaluated at this time.

Storage

To ensure maximum performance when needed, VESPEL® parts and shapes are best stored under normal, indoor, ambient conditions. Temperature should not exceed 40°C. No exposure to sunlight, UV-light or other form of radiation and no direct contact to water and chemicals is recommended.

Limited Oxygen Index (LOI)

ASTM D2863

Definition:

LOI is the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen that will just support flaming combustion.

VESPEL® SP1	53% O_2
VESPEL® SP21	49% O_2

Hot wire ignition, UL 746 A

VESPEL® SP1, SP21, SP22 and SP211 are rated 0 at 1,6 and 3,2 mm thickness. ST products have not been evaluated at this time.

Direct forming

Production quantities of VESPEL® precision parts can be more economically fabricated by the DuPont-developed direct-forming process. Direct-forming utilises powder metallurgy techniques to produce precision parts or blanks which are nearly identical to those machined from solid stock with the advantage that material wastes are either eliminated completely or minimised. In most cases, the forming process is so precise that the parts require no secondary machining.

While there are no rules concerning minimum order size since each job is considerd individually, economics are usually realised with 1000 or more units per order.

The precision dies used to form the parts are bought and owned by DuPont. However, the customer is charged initially for the engineering and development work required to design and test the tooling.

Direct-formed parts do have limitations. Not all shapes and sizes can be formed, although many parts once considered impractical are now routinely made.

One-level parts such as bushings and discs, with or without holes, or any contour that can be pressed with identical single upper and lower punches are made routinely. Core pins are used to form holes of any radial contour that can be machined into the pin and mating tool surfaces. Flats, splines and gear shapes can be formed as readily as round holes. In some cases, blind holes (such as a cap part) can be provided. A small step or indentation can be formed into flat part subject to limitation described in "Design Consideration".

Multilevel parts require multiple pressing motions since powder does not readily flow from one level to another. Two-level parts such as a flanged bushing can be produced. Such parts would require two lower and one upper pressing motion. Parts which have more than two levels usually require secondary machining.

Part geometry must permit ejection from the die. Undercuts, holes at right angles to the pressing direction, reverse tapers, reentrant angles and threads cannot be pressed. But, often features that cannot be formed into the part can be machined without losing all of the economic advantage offered by direct-forming.

Wall thicknesses are a function of the part height. A higher part requires a thicker wall because the powder must flow into the die cavity and fill it equally.

Chamfers, when required, should be angled no more than 30° from the horizontal, i.e. right angle to pressing direction. Chamfers of 45° are produced, but tool life is shortened. Chamfers require that punches have a 0–0,3 mm flat (skirt) to avoid a feather edge.

Parts can be direct formed as thick as approximately 58 mm.
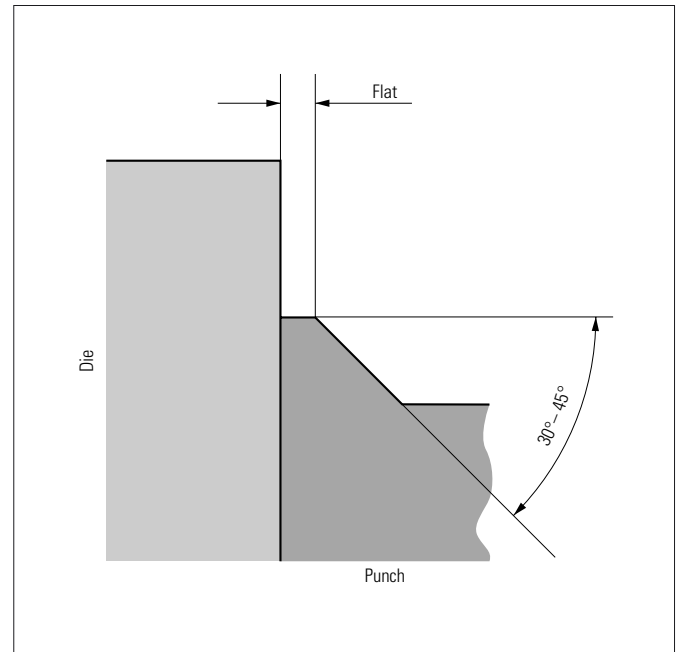
The physical properties of direct-formed VESPEL® precision parts will differ slightly from the properties of VESPEL® parts machined from a basic shape.

For most applications, the designer need not be concerned about this slight difference in property values. However, when critical applications are involved, we suggest you test with the actual direct-formed part.

Direct-formed parts

The direct formed process developped by DuPont usually is carried out in two steps.

Fast running vertical toggle-joint presses equipped with pressing dies produce die-formed parts from polyimide powder. This is very similar to the ceramic powder pressing operation. But due to much tighter tolerances the pressing process has to be strictly controlled and kept within narrow parameters. Powder flow and elastic behaviour have to be considered to ensure homogenous density and stable dimensions.

The product out of this process is a solid part, made from polyimide powder, with specific ingredients, determined by the requested properties under the conditions of the end-use.

The green parts can be handled in big lots in crates or containers without suffering any damage to be forwarded to the following sintering process.

Being stored in metal containers the parts go into big sinter ovens. Sintering takes place at high temperatures. Measures are to be taken to keep the oxygen away at the elevated temperatures. After a few hours the sintering is completed and the parts have got their final properties.
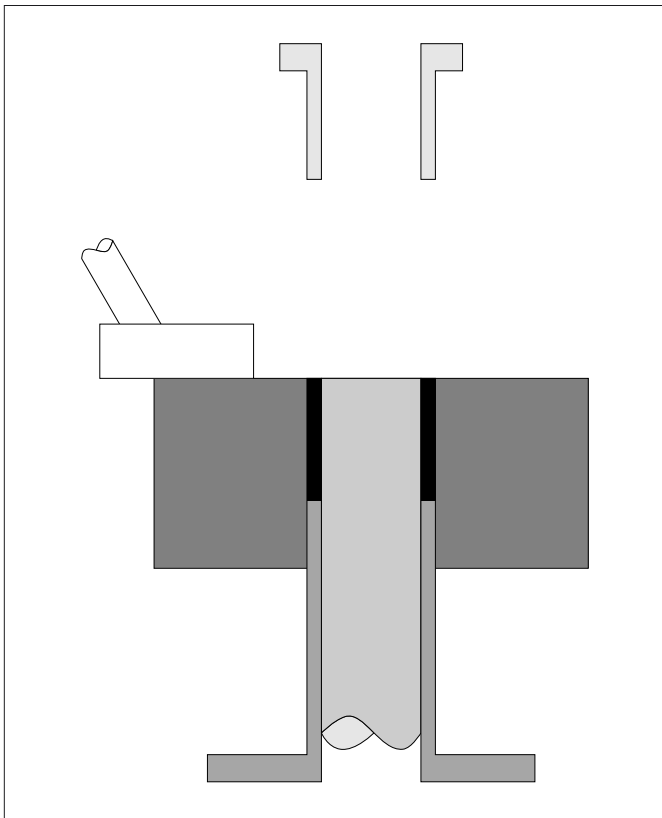
1. The filling shoe is moving back after the powder has been filled into the die. The upper and the lower punches are moved to their top and bottom position.
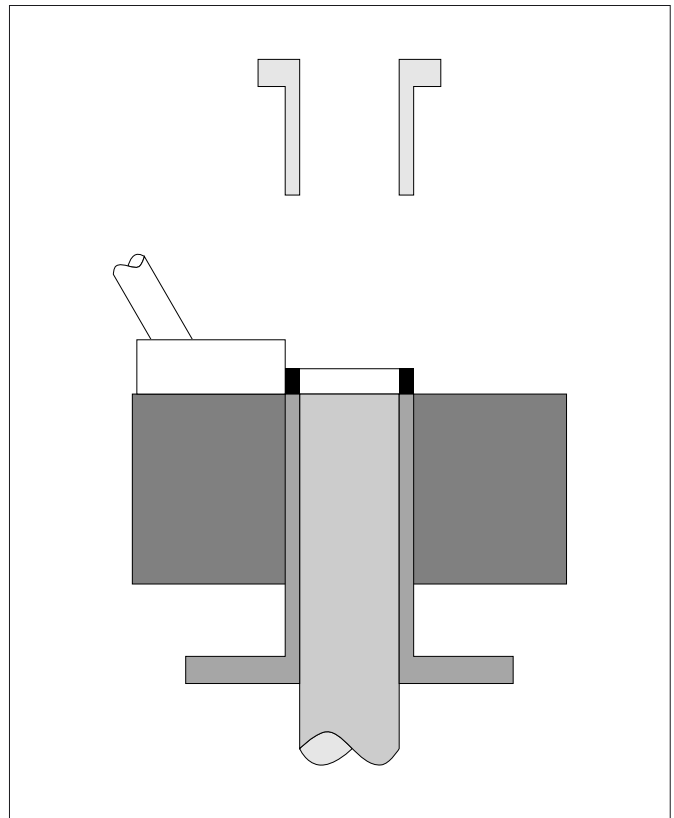
3. The upper punch is moving up while the lower punch is punching the pressed "green part" out of the die.
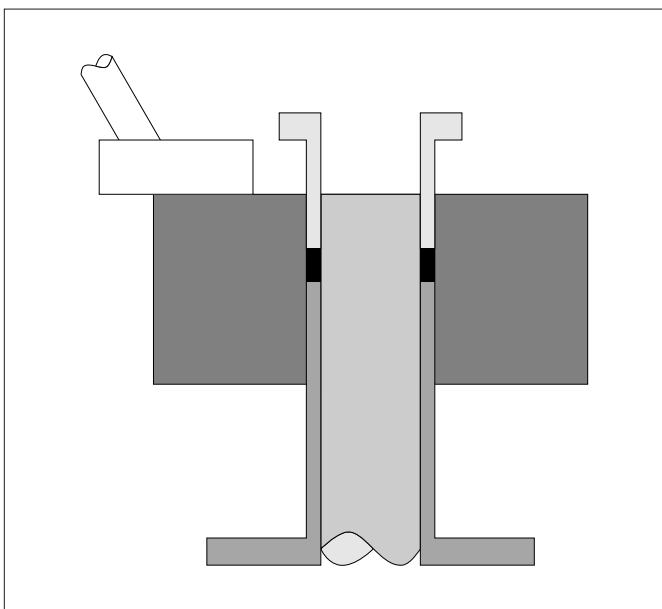
2. Upper punch and lower punch are moving towards each other to compact the powder and press the part.
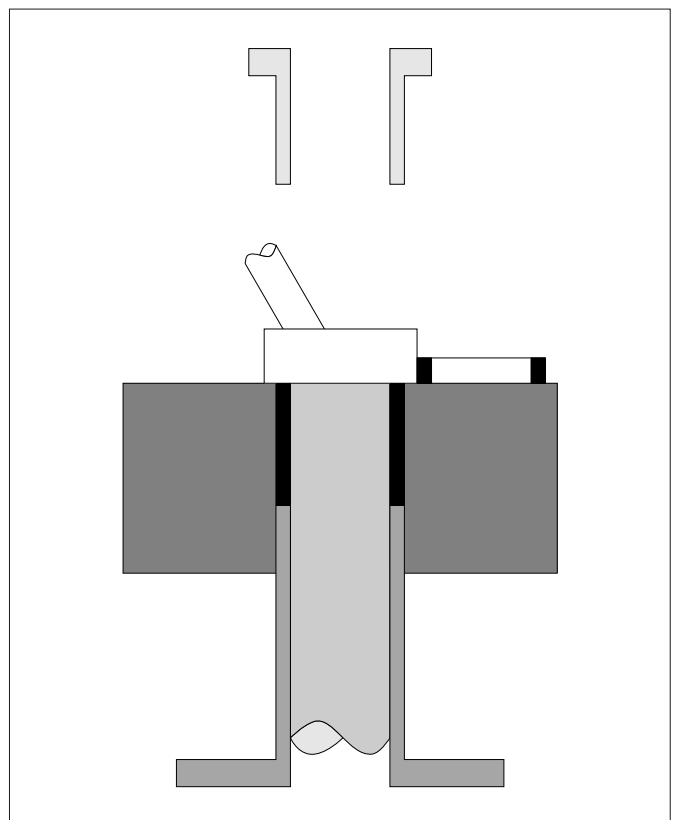
4. The lower punch is moving down while the filling shoe moves over the die to fill it with powder. Simultaneously the lifted part is pushed away from the tool.

During sintering the parts shrink according to size and shape and pressing direction. This shrinkage must be considered when the die is being designed and made. It takes a lot of knowledge and experience as different additives influence the three dimensional shrinkage additionally.

During shrinkage some more changes take place. The green part necessarily reflects features and toolmarks of die and punches. While sintering all surfaces change slightly to a rolling profile with a roughness of approximately Rz 7 (metric, DIN 4786). A cross section of the roughness profile shows under the microscope a surface which is similar to soft sinus lines. This enables VESPEL® to work in contact with metal parts in sliding bearings without additional machining of the bearing surfaces.

All sharp edges of the green part get rounded to a shape similar to a radius of 0,05 mm. This feature is very useful as it is not necessary to design parts with chamfers like designers would use on metal parts.

According to customer's specification the parts undergo final inspection and documentation and are ready either for additional machining or packaging and shipment.

Direct forming capabilities

Thinnest part	~1 mm
Thickest part	~58 mm*
Largest OD	~300 mm
Minimum ID	~0,5 mm
Largest surface area	~2800 mm^2
	can be increased by heated process to ~7000 mm^2
Surface finish	~1 µm (Ra)
Flat on chamfers	0-0,3 mm

PRESSING

DIRECTION
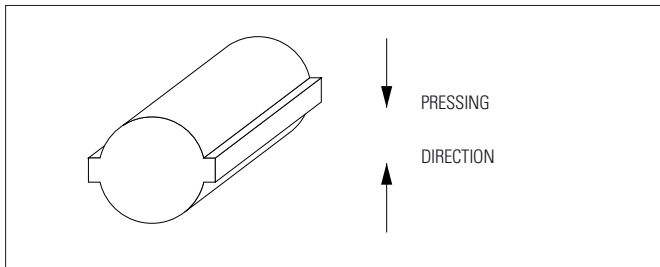
* Cylindrical parts longer than 58 mm may be pressed horizontally instead of vertically. However, these parts will have 2 flats (see sketch).

Tolerances and general design guidelines

Tolerances and design guides for typical direct-formed parts are presented below. However, each part is considered individually, so that variations and exceptions can be made, depending on the function of the part and its operating environment.

Standard level of tolerances

Dimension	Standard tolerance
Diameters, mm	µm
7,5 - 12,5	± 40
12,5 - 19	± 50
>19	± 65
Height, mm	µm
0,4 - 2,5	± 75
2,5 - 6,5	± 100
6,5 - 12,5	± 125
12,5 - 25	± 150

WALL WIDTH

H

I.D.

O.D.
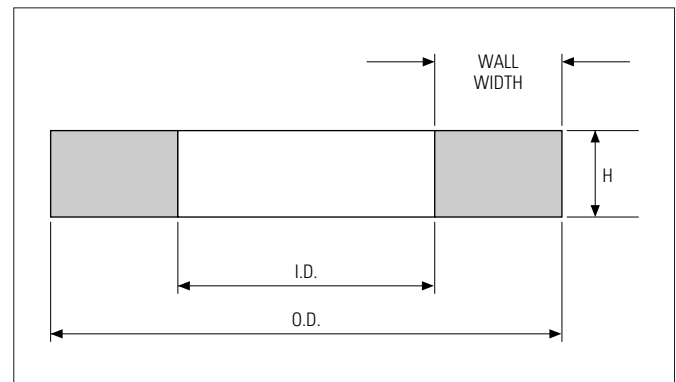
Please note: To make optimum use of VESPEL® tolerance capabilities do not specify OD and ID, but the most important diameter only and the wall thickness!

Additional tolerance guidelines (in mm)

Diameter	⊙ Concentricity	→ Roundness	// Parallelity	◱ Flatness*
< 25,4	0,040	0,050	0,040	0,050
25,4-50,8	0,050	0,125	0,075	0,125
> 50,8	0,050 +[1]	0,125 +[2]	0,075 +[3]	0,125 +[2]

1 = 0,0005* (d-50,8) mm   * For simple parts
2 = 0,005* (d-50,8) mm
3 = 0,001* (d-50,8) mm

Design considerations

A

0-0,3
Flats on Chamfers

D

H

D

ø (30° ± 2° Recommended)

D max = 0,15 H

H

D max = 0,3 H

B

Simple parts such as bushings or washers which can be formed with flat punches cause less breakdown time.

C

45° Min.

AVOID

Preferred 60°

0 – 0,3

D

H

D

PREFERRED

a. Chamfers with angles 45° or less from the vertical should be avoided.
b. Flats (0-0,3 mm) are required at the base of all chamfers with angles from 45°-60°.
c. Depth "D" of a chamfer or the total depth of chamfers on both ends of a part is limited to a maximum of 30 % of the part height "H".

D

1,25 Min.

15° Max.

An acute angle (15° maximum) for a lead-in can be formed in the compacting die in most cases. A small parallel portion (1,25 mm minimum) is required above the acute angle to prevent jamming of the top punch.

E

a.

AVOID

b.

PREFERRED

a. Undercuts cannot be formed into a part.

b. A radius (0 to 0,5 mm) is required between the flange and the hub of the part.

AVOID

PREFERRED

F

See Detail

0,3 H Max.

H

Detail

R

r   r   Typical

Curved or semicircular grooves can be formed to a maximum depth of 30 % of the total part height.

G

a. Parts with reentrant angles cannot be formed.

a.

AVOID

b. The part must be formed parallel and machined to shape.

b.

PREFERRED

H

a. Parts with a minimum wall thickness of 1 mm are recommended, although parts with wall thicknesses of 0,65 mm can be produced. Minimum wall thickness is a function of part height.

a.

AVOID

b. The size of the square has been decreased to increase the wall thickness. The OD of the circle could have been increased to achieve the same effect.

b.

PREFERRED

c. Alternate ways to increase wall thickness.

Rad.

c.

I

1

2

a. Avoid sharp edges which weaken the die (1) and sharp corners which weaken parts (2).

AVOID

1

2

b. Radiused edges (1) and radiused corners (2) add strength to tools and parts.

PREFERRED

J

a.

a. Profiles requiring feather edges on punches should be avoided.
Holes should not be less than 2 mm diameter.

AVOID

b. Part re-designed for stronger punches and hole large enough for forming.

2 mm

PREFERRED

Direct-formed secondary machined parts

As direct-formed parts are pressed on vertical presses the design of those parts is limited by the one-dimensional stroke of the press.

Because of this there are some limitations to the shape of the die-pressings. The parts can not have undercuts perpendicular to the pressing direction. These would not allow the part to be ejected after the pressing stroke.

Differently to many polymers VESPEL® is easy to machine with all usual machine tools. Any cutting operation can be carried out easily and will yield very smooth surfaces.

Machining can be done on customer's request either by DuPont or by any machine shop determined by the customer.

Generally, tolerances of quality 8 can easily be achieved by machined VESPEL® parts. (See Appendix B for ISO tolerances).

Machined parts

VESPEL® shapes are made by DuPont from high-performance SP polyimide resins, and are available as rods, tubes, plaques, rings, discs and bars. (See Appendix A).

Parts machined from VESPEL® shapes are ideal for prototype, low volume or complex geometry parts. Keep in mind, though, that if you need more than 1000 parts at a time, they can often be manufactured more cost effectively by DuPont using our "direct-forming" process.

27

It is very important, testing Vespel® in an application, to use the material (either shape or direct formed) that will be used commercially. For this reason DuPont offers direct formed material (slugs) for prototyping.

Shapes out of ST polyimide resins are not yet available.

General machining procedures

Vespel® shapes are relatively easy to machine because of their inherent mechanical strength, stiffness and dimensional stability at machining temperatures. In addition, they can be machined with standard metal-working equipment to produce parts to tolerances once considered too close for plastic materials. In most cases, the techniques used in machining metals are directly applicable.

Suggested tooling

- **Carbide tooling:** C-2 grade.

- **Kennametal K-11, Carbaloy 895** or equivalent: When tool life is particularly important.

- **High speed steel:** For short runs on multiple-point tools such as end-mills, countersinks and reamers.

Special considerations

- **Overheating:** Do not allow the material to get so hot that it is unconfortable to grasp with your bare hands. If overheating occurs, resharpen the tool and/or reduce the feed rate.

- **Light work:** Use tools that work well with brass.

- **Tool chatter:** Tools should have a 0° to 5° positive side rake angle and 0° back rake angle to reduce the possibility of tool chatter.

- **Special sizes:** Large diameter or thin wall Vespel® parts have been sucessfully machined to close toler-ances. To maintain dimensional stability, the part can be rough-machined to within 0,4-0,5 mm of finished size, then equilibrated to 23°C and 50% relative humidity before final machining.

Holding

The main precaution in holding Vespel® shapes for machining is to prevent any deflection caused by the holding fixture, collet or chuck. Unlike metal, plastics, including Vespel®, will deform if held too tightly.

Reliable holding methods

- **OD or ID collet:** This is the most reliable holding device with sufficient pressure to sensure a good hold.

- **Chuck:** Six-jaw tape is suggested to distribute the holding force.

Sawing

Vespel® shapes cut easily with either circular or band saws. Follow these suggestions for best results:

Circular sawing

- Use a sharp blade without "set".

- A 254 mm diameter saw with 3-5 teeth per cm operating at a surface speed of 1800-2400 m/min with water as a coolant has been successfully used to cut 75-mm thick Vespel® stock.

Band sawing

- Sections of Vespel® 125 mm thick can be cut on a band saw without coolant, using a sharp 4 teeth/cm blade with standard set.

- Finer blades can be used for cutting thinner sections.

- Use special alloy blades for most filled compositions.

Turning

To produce good machining finishes on turned Vespel® pieces, follow these suggestions:

- Turn using standard lathe, chucker or screw machine techniques.

- Use carbide-tipped tools for work requiring close tolerances.

- Chip-breaker designed tools work well.

- Keep tool cutting edge sharp, with a nose radius of 0,08-0,2 mm. Ensure sharpness by examining the cutting edge under $10 \times$ magnification, and hone the edge and nose radius with an 800-grit diamond hand hone if necessary.

- Speeds in the range of those used in the machining of brass are suggested. Stock speed can be varied over a wide range with good results.

- A coolant may be used to minimise thermal effects and maintain dimensional stability.

- Chattering could indicate a dull cutting tool.
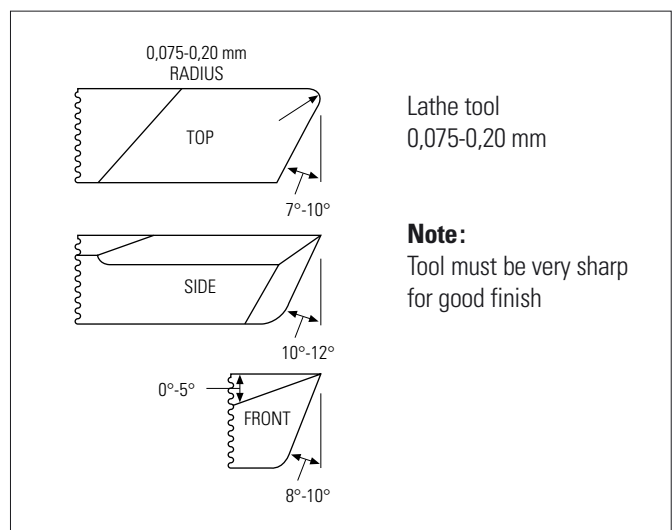
Lathe operating conditions	Cross feed per revolution mm
Rough turning and facing	0,25 -0,50
Finish turning and facing	0,25 -0,05
Rough boring	0,50 -0,1
Parting	0,075-0,20

Milling

In general, milling operations which are used on metals may be used on VESPEL® shapes. Exercise the same precautions regarding heat build-up, care in holding, sharpness of tools, avoiding dust inhalation, etc.

Avoid edge chipping by:

• Backing up edges with some other material.

• Climb milling.

• Slowing cross feed to no more than 50 mm per minute when breaking through an edge.

• Using fly cutters whenever possible, as they work especially well.

Avoid chipout

To drill thin cross sections without chipout, follow these suggestions:

• Use a drill with a 5° end relief or end mill. Feed automatically, if possible, or ease off feed pressure at breakthrough. Cutting speeds of 12-15 m/min should produce acceptable results.

Drilling

VESPEL® parts are more elastic and have a higher coefficient of thermal expansion than metal; because of this, they have a greater likelihood of seizing than metal. Depending on your application, the following drills and drill modifications can reduce the possibility of seizing.

Modified drill for VESPEL® shapes

Modified drill for VESPEL® shapes 19 mm drill dia. Diameter reduced by approx. 3 mm. 3 mm approx. sharp cutting lips. Included angle: 90°-115°. Lip clearance: 25°-30°. On drills: 25 mm diameter reduction of web thickness may be desirable.

19 mm drill dia.
Diameter reduced by approx. 3 mm
3 mm Approx.
Sharp cutting lips
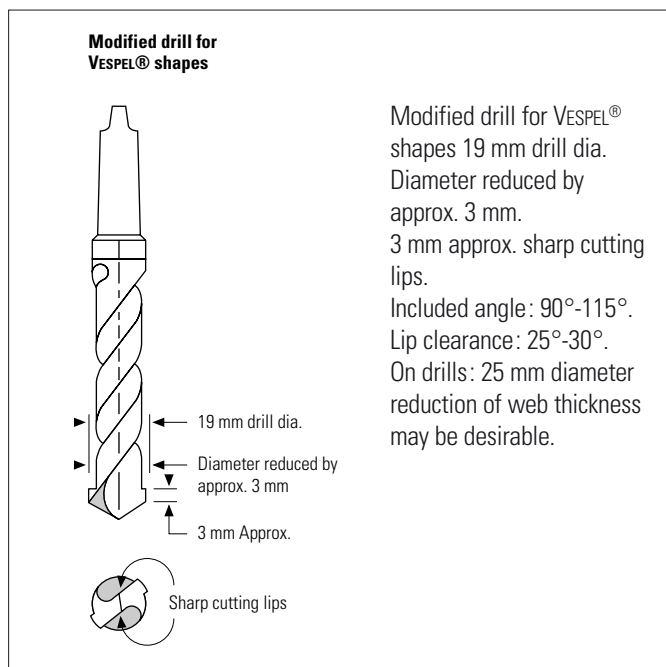
It might happen that burrs are present at the end of the hole after drilling. A second machining step can therefore be necessary to remove them. Unless, refer to paragraph **Deburring.**

• **Standard twist drill**

   May be used to drill shallow holes (up to about one-half of the drill diameter in depth). Drilling holes deeper than one-half the drill diameter increases the risk of seizing.

• **Modified drill**

   Differs from standard twist drill in several ways:

   Diameter is reduced along the full length of the drill body except for the leading 3 mm behind the lands.

   Lip clearance is increased to 25-30° (vs. standard 12-15°).

   On drills, 25 mm diameter and larger, the thickness of the standard drill web could be reduced.

   Allow rates normally employed in cutting mild steel so that holes cut have good surface finishes.

• **Spade drills**

   Give good surface finishes and reduced chipping when drill breaks through to other side.

Blind holes

Deep blind holes are difficult to manufacture to close tolerances. Rough drill bore whenever possible. Gun drills may be used with high pressure coolant to help remove chip buildup.

Threading

VESPEL® shapes can be threaded using standard metal-cutting taps. Take care to keep material from heating to a point where thermal expansion will cause binding of the tap. If facilities are available, threads should be chased using a single point carbide tool and 30° compound feed whenever possible. The depth of feed should not exceed 0,13 mm on first pass and gradual reduction to 0,05 mm per pass until complete. Although this procedure will add additional cycle times to individual part production it assures good thread quality results.

Reaming

As with drilling, reaming VESPEL® shapes requires a modified tool, such as the one shown below, to avoid seizing. Reaming may produce a tapered hole 0,025-0,05 mm larger than desired because of temperature buildup. For closer tolerances, boring is better. At least 0,4 mm should be left to be removed in the boring operation. Deep on-size holes can be reamed and bored with techniques normally employed in cutting mild steels.

Modified reamer for VESPEL® shapes

Diameter reduced by approx. (3 mm)

19 mm Reamer dia.

3 mm Approx.

Margins and relief angle same as for mild steel.
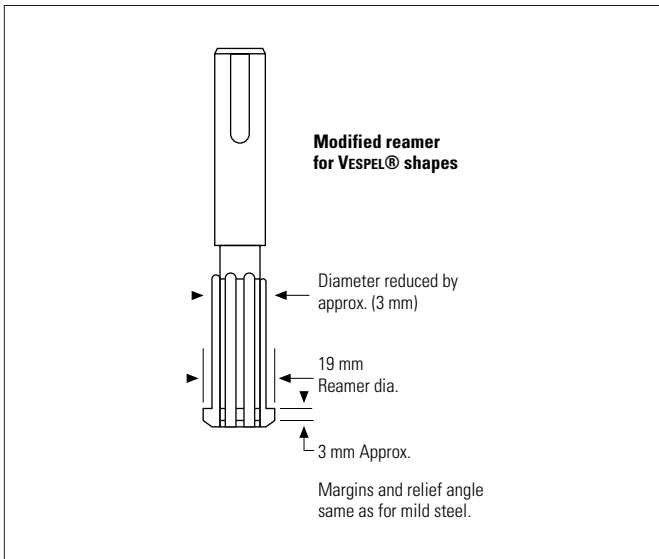
Grinding

VESPEL® shapes can be ground to close tolerances on surface, double disc or centreless grinders at a table surface speed of approximately 24 m/min for rough cuts and about half that for finish grinding on surface grinders. A 305 mm diameter 32A46-H8VG wheel works well at surface speeds of 900–1200 m/min. The wheel should be diamond dressed as for finish grinding of steel.

VESPEL® rods and small tubes can be prepared for chucker and screw machine stock by centreless grinding. Standard setups used for steel with plenty of coolant flow are usually adequate.

Caution: Do not allow material to get hotter than is comfortable to handle with your bare hands.

Buffing and polishing

VESPEL® parts can be polished to a high gloss with conventional muslin wheels. No special precautions are necessary beyond those normally practiced in this operation.

Deburring

Burrs can be removed using the same methods used on metal parts. VESPEL® parts may also be tumbled in vibratory or rotating deburring equipment, along with abrasive media, tumbling detergent and water.

Lapping

To avoid impregnating VESPEL® shapes with diamond or aluminium oxide compounds, follow these lapping suggestions for flat, highly polished surfaces.

• Use a wet or dry abrasive paper (such as 600-grit Norton Tufbak Durite) where the grit will be contained.

• Use a granite surface plate or equivalent to maintain flatness.

• Light machine oil can be used as a vehicle.

• Final lapping with Crocus Cloth will result in a finer finish.

• Additional surface polish can be obtained by lapping the VESPEL® shapes on Kraft or tablet paper.

Safety precautions for machining TEFLON® filled SP211

VESPEL® parts and shapes made from SP211 resin contain 10% TEFLON® PTFE resin by weight and PTFE particles can become airborne during machining operations. Follow these precautions:

• When machining or cutting, use coolant – preferably cutting oil or water soluble coolant oil. Do not sand SP211 without adequate ventilation equipment.

• Keep materials for smoking, such as cigarettes and pipes, out of the immediate machining area, as airborne particles of PTFE may contaminate them.

• Avoid inhaling dust, and wash hands thoroughly before smoking or eating.

See Material Safety Data Sheet in Appendix C.

Measuring parts

Although the same tools used to measure metal parts can be used to measure VESPEL® parts, techniques differ because of the possibilities of greater deflection of plastic parts under the stress applied during measurement. Parts should be conditioned in accordance with ASTM D 616, Procedure AA, in which test specimens are allowed to remain at a standard laboratory atmosphere for a minimum of 40 hours (23°C with a relative humidity of 50% ± 5%).

Micrometer

When measuring the OD of a ring, do not use the micrometer in the usual fashion (twisting the barrel until it feels snug or until the ratchet slips) as this may actually deform the part, causing an incorrect reading. Rather, set the micrometer at the minimum reading of the tolerance and try passing the part through the gap, using the micrometer as a "go" gauge. The part should pass through without any pressure applied. To minimise distortion of thin-walled cross sections, a correctly-sized ID plug may be inserted into the part.

Plug gauge

When measuring hole sizes with a plug gauge, avoid forcing the plug into the hole, as it is entirely possible to force a plug gauge into a hole as much as 0,1 mm under the plug gauge size, depending on the part design. Generally, plug gauges are better than hole micrometers because of the deformation the micrometers may cause. Air gauges work well for measuring internal diameters.

More accurate measurements will be achieved by using optical or touch trigger probe devices.

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Annealing

Annealing, or heat treating, of VESPEL® is a procedure intended to relieve stresses introduced into the material from processing and/or machining. This relief comes during heating of the material to some temperature where the molecular structure can move or change from a state of higher stress to a state of lower stress. There is normally an accompanying reduction in the volume of the material.

The stresses present in the various forms of VESPEL® can be from their differencies in processing or from some plaque or rod. The objective in relieving these stresses is to gradually heat the material to some level above its expected maximum operational temperature, hold at that temperature to ensure uniformity of heating throughout the material and then to cool gradually to reduce the possibility of thermal stressing.

Because VESPEL®, like most polymeric materials, will undergo some thermal or oxidative degradation above some temperature limit it is appropriate to carry out any annealing in either a vacuum oven or an inert gas purged oven.

Annealing procedure

Note: Always test this procedure on one or a few parts to ensure adequate material is allowed for dimensional change.

After annealing the part should be able to undergo exposure to maximum operating temperature without additional dimensional change.

1. Machine VESPEL® to within 0,5 to 1,5 mm of final dimensions.
2. Introduce material into vacuum or inert gas purged oven at room temperature.
3. Heat material at a rate of 1 to 1,5°C per minute to a temperature of 20°C above the expected maximum operating temperature. We suggest a minimum annealing temperature of 150°C for any parts with expected service temperature of 120°C or less.
4. Hold the material at that maximum temperature for two hours (material with a minimum dimension of 25 mm or greater should be held for three hours).
5. Turn off the heat to the oven and allow the material to cool gradually to 70°C in the closed oven before removing material.
6. It has been demonstrated that the ideal time to anneal is just prior to any final machining on the part. Multiple annealing is not necessary.
7. All temperatures should be within ±3°C.

Plaque, rod, tube and bar stock by nature of their processing should be annealed if dimensional tolerances are to be held closer than 3% and thermal exposure is anticipated. Any shape or part that has been machined will require annealing for close tolerance control.

Annealing above 370°C is not recommended. Thermal damage can occur and thermal expansion is probably greater than change in dimensions as a result of stress relief.

Bonding

A variety of adhesives can be used to join VESPEL® parts to themselves or to other plastics, metals and elastomers. Choice of an adhesive depends on the particular application, especially on end-use temperature. Cleanliness of the surfaces to be adhered and strict observation of the adhesive manufacturer's recommendations are essential for good results. Surfaces to be adhered should have reasonably matching contours since optimum adhesion requires a thin, uniform thickness of adhesive.

Types of adhesives

Epoxy, phenolic and polyimide adhesives have been used successfully with VESPEL® parts.

Surface preparation of VESPEL® parts

Only mechanical etching by abrasive blasts should be used in preparing VESPEL® parts surfaces for adhesion.

Surface contaminants such as dirt and oils should be removed with solvents. Cleaning in refluxing perchloroethylene is recommended.

Overmoulding and coating

As VESPEL® does not melt it may be beneficial for complex or big parts to overmould a VESPEL® insert by another injection mouldable engineering polymer.

Using the superior VESPEL® properties the area where it is needed – while the rest of the surrounding part is of an injection moulded material – may offer the most cost effective solution to your technical requirement.

The high performance VESPEL® parts may also be coated, for example with TEFLON®, to provide additional specific properties.

Radiation resistance

This brief overview shows that VESPEL® parts can perform well in different radioactive environments, even at relatively high dosage rates. The small losses in weight, tensile strength and elongation properties, at doses up to 1×10^8 rads, suggest that the superior properties of VESPEL® parts may be used even in environments containing gamma or electron beam radiation.

Working with radiation

Radiation from various sources may be present in the environments of a number of technical and industrial applications. At high radiation levels, it is often necessary to use remote handling or automatic equipment to avoid injury to personnel. Materials used in the construction of such equipment must be able to withstand exposure to radiation.

While metals perform well in static structures, the necessity for lubrication, with the consequent possibility of contamination from the lubricant, reduces their usefulness in bearings, bushings and sliding surfaces. For applications requiring moving parts, as in the handling systems for the production of radiochemicals, or the handling of nuclear fuel rods, self-lubricating high performance polymers such as VESPEL® SP polyimide parts can overcome some of the limitations of metals.

The performance of VESPEL® SP polyimide parts when subjected to different kinds and levels of radiation is described below.

Testing

To determine how well direct-formed VESPEL® bars (SP1, SP21 and SP22) performed after radiation exposure, three parameters were evaluated:

1. weight loss;

2. change in tensile strength; and

3. change in elongation, compared to randomly selected control bars which received no radiation exposure.

Gamma radiation was provided at a dosage of $3,8 \times 10^6$ rads/hour from a cobalt 60 source. Exposure times of 16 minutes, 2,6 hours and 26,3 hours resulted in total dossages of 10^6, 10^7 and 10^8 rads.

Electron beam radiation from a 2,0 MV Van de Graaf generator provided a dosage rate of $4,0 \times 10^6$ rads/hour. Exposure times of 1,6 minutes, 80 minutes and 2,7 hours resulted in total dosages of 10^6, 5×10^7 and 10^8 rads.

Neutron beam radiation was provided by a neutron flux of 5×10^{13}/cm²/second. Tensile bars were subjected to this exposure level for 100 and 150 hours respectively. Co-incident gamma radiation, at an average dosage rate of $1,2 \times 10^8$ rads/hour, accompanied the neutron beam exposures.

VESPEL® parts and gamma radiation

Weight loss

At exposure levels up to and including 1×10^8 rads of gamma radiation, VESPEL® bars displayed less than 1,0% weight loss.

Tensile strength

VESPEL® tensile bars showed less than 6,5% loss in strength up to the maximum exposure level of 1×10^8 rads.

Elongation

All three VESPEL® formulations showed small changes in per cent elongation at break. The most significant loss (19,2% from controls) occurred at the highest level of gamma exposure.

VESPEL® parts and electron beam radiation

Weight loss

At exposure levels up to and including 1×10^8 rads of electron beam radiation, VESPEL® bars displayed less than 2,0% weight loss.

Tensile strength

VESPEL® tensile bars showed less than 4,5% loss in strength up to the maximum exposure level of 1×10^8 rads.

Elongation

All three VESPEL® formulations showed small changes in per cent elongation at break. The most significant losses measured less than 15,0% from controls for the highest level of electron beam exposure.

VESPEL® parts and neutron beam radiation

Although none of the test bars swelled or were noticeably distorted, tensile strength was substantially reduced after the exposure to high levels of neutron beam irradiation. Therefore, we suggest that you discuss applications involving neutron radiation with a VESPEL® Sales Engineer and that you perform specific exposure tests.

Bushings and bearings

The earlier you "think VESPEL®", the more cost-effective your total design can be

The engineers and sales staff at DuPont's VESPEL® Division are ready to help you make the best use of the superior performance of VESPEL® parts. Just write to the VESPEL® Sales Office nearest you, or call your VESPEL® Sales Engineer.

Putting VESPEL® to work in your system

DuPont VESPEL® SP polyimide bearings have been hard at work for more than twenty years, keeping equipment running longer and with less maintenance than conventional bearing materials.

VESPEL® bearings are the cost-effective choice in thousands of applications, because they are tough, lightweight and resist wear and creep – even at extremes of temperature. They can outperform metals and other engineering plastics under a wide range of conditions.

This design chapter is provided to help you choose the VESPEL® bearing that is best suited to your application. Inside you will find:
- general information about bearing design;
- a method for determining pressure-velocity (PV) loading in your application;
- guidelines for selecting the correct SP polyimide for PV loadings found in practice;
- considerations for use in the design of VESPEL® bearings, and
- a sample bearing design problem.

VESPEL® bearings vs. other materials

The ability of a bearing to perform in a given application depends, in general, on:
- the operating environment, including temperature and lubrication;
- load or pressure on the bearing surface;
- sliding velocity of the mating surfaces relative to the bearing;
- hardness and finish of the mating surface;
- friction behaviour of the bearing material;
- thickness of the bearing material combined with the material's ability to dissipate heat of friction.

VESPEL® parts, made from DuPont's polyimide resins, perform well with or without lubrication under conditions that destroy most other plastics and cause severe wear in most metals. VESPEL® bearings reduce or eliminate problems with abrasion, corrosion, adhesion, fatigue and wear that plague conventional bearing materials, especially when used without lubricants.

VESPEL® bearings can accommodate higher pressure-velocity (PV) loading than most high-performance engineering plastics. In addition, VESPEL® bearings excel over a wide range of temperatures and stresses because they retain their outstanding creep resistance, abrasion resistance and strength. They have performed successfully in the following adverse environments:
- air and inert gases at 370°C;
- gamma and electron beam radiation;
- high vacuum (10^{-10} torr);
- hydraulic fluids and jet fuels;
- liquid hydrogen.

Unlike ordinary ball, needle and roller bearings, VESPEL® bearings:
- need no external lubrication;
- perform at temperatures where lubricants break down;
- perfom well in dirty environments;
- can reduce noise, weight and costs.

Compared with bronze, brass and porous metal bearings, VESPEL® bearings:
- extend the life of other components by eliminating metal-to-metal wear;
- withstand combinations of temperature, pressure and surface velocity beyond the reach of unlubricated metals;
- resist creep and poundout:
- eliminates problems of lubricant loss in the presence of paper dust or lint.

Compared with other polymer bearings, VESPEL® bearings:
- perform at temperatures, pressures and surface velocities that other plastics cannot survive;
- increase creep and poundout resistance;
- machine like brass and hold tighter tolerances.

How to choose a bearing material

PV loading – a prime factor in material selection

PV is the product of load or pressure (P) and sliding velocity (V). A plastic bearing subjected to increasing PV loading will eventually reach a point of failure known as the PV limit. The failure point is usually manifested by an abrupt increase in the wear rate of the bearing material.

As long as the mechanical strength of the bearing material is not exceeded, the temperature of the bearing surface is generally the most important factor in determining PV limit. Therefore, anything that affects surface temperature – coefficient of friction, thermal conductivity, lubrication, ambient temperature, running clearance, hardness and surface finish of mating materials – will also affect the PV limit of the bearing.

The first step in evaluating a bearing material consists of determining whether the PV limit of that material will be exceeded in your application. It is usually prudent to allow a generous safety margin in determining PV limits, because real operating conditions often are more rigorous than experimental conditions.

Determining your PV requirements

1. First determine the static loading per unit area (P) that the bearing must withstand in operation.

   P   = pressure, MPa
   W   = static load, N
   d   = bearing surface ID, mm
   B   = bearing length, mm
   N   = rotation speed, rpm
   D   = bearing surface OD, mm

For journal bearing configurations: $P = W / (d \times b)$
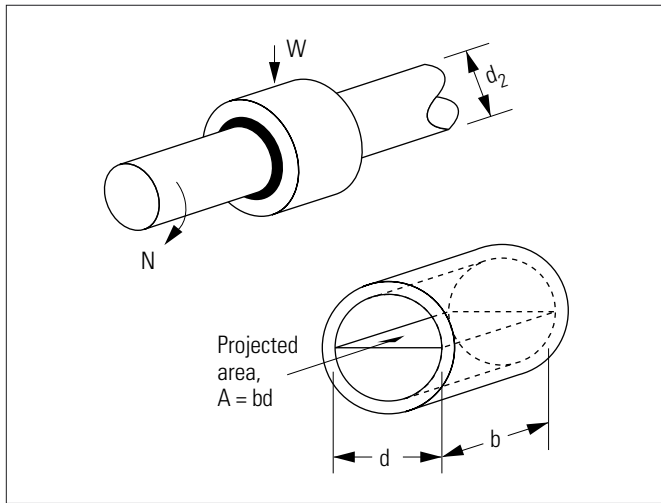
For thrust bearing configurations: $P = 4W / \pi (D^2 - d^2)$
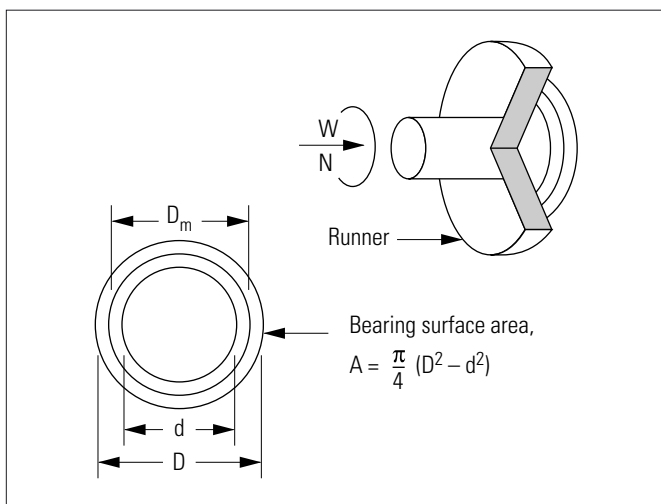
For either bearing configuration, pressure (P) should not exceed the values shown here at room temperature:

Allowable static bearing pressure

Composition	SP1		SP21	
Fabrication process	Mach.	Direct formed	Mach.	Direct formed
P, MPa	51	33	46	34
Composition	SP22		SP211	
Fabrication process	Mach.	Direct formed	Mach.	Direct formed
P, MPa	41	26	37	28

2. Next, calculate the velocity (V) of the bearing relative to the mating surface:

	Journal bearing	Thrust bearing
Continuous rotation	$V = \pi (dN)/60$	$V = \pi (D_m N)/60$
Oscillatory motion	$V = \pi (dN) (\theta/180)/60$	$V = \pi (D_m N) (\theta/180)/60$

where:

N   = speed of rotation, rpm or cycles/min
D_m = $(D + d)/2$, m
θ = angle between limits of oscillation, degrees
V   = surface velocity, m/s

3. Finally, calculate PV:

   $PV (MPa \cdot m/s) = P (MPa) \times V (m/s)$

PV limits of unlubricated bearing materials

Table 6 shows the maximum PV limits for unlubricated VESPEL® parts and several other unlubricated materials under conditions of continuous motion.
Properly lubricated VESPEL® parts can withstand approximately 40 MPa · m/s.

Table 6   PV limit guidelines**

Material	Filler	MPa · m/s	Maximum contact temperature (°C)
SP21	15 % graphite	12	395
SP22	40 % graphite	12	395
SP211	15 % graphite 10 % PTFE	3,6	260
PTFE*	Unfilled	0,064	260
PTFE*	15–25 % glass	0,45	260
PTFE*	25 % carbon	0,71	260
PTFE*	60 % bronze	0,66	260
Nylon	Unfilled	0,14	150
Acetal	PTFE Unfilled	0,27 0,12	120

* At 0,5 m/s.
** These guideline values are supplied for reference only. PV limits for any material vary with different combinations of pressure and velocity as well as with other test conditions. Consult manufacturer's literature for detailed information.

Designing VESPEL® bearings

Effect of surface temperature on wear characteristics

PV is a very useful measure in determining the suitability of a material for a bearing application. However, contact pressure and sliding velocity alone do not adequately characterize bearing materials. Temperature, system geometry and mating surface material also play significant roles in wear of bearings.

Of the factors just named, temperature is generally the most important, because it not only affects the coefficient of friction but also determines the usable combinations of pressure and sliding velocity, or PV. Wear characteristics of VESPEL® bearings will be moderate even at high PV's if sufficient cooling is provided. Wear can be severe at any PV if the ambient temperature is too high. The wear resistance, which is a system property (tribological system) and not only a material property of a VESPEL® bearing operating at a temperature below its limit can be predicted from an experimentally determined Wear Factor. The wear factor is derived from an equation relating the volume of material removed by wear in a given time per unit of load and surface velocity.

$$v = f\ (KFVT)$$

where:

v = wear volume, mm^3

K = wear factor, mm^3/Nm
   function of mating material roughness and hardness, temperature and environment

F = supported load, N

T = time, s

V = velocity, m/s

For flat surfaces the equation is modified so that:

$$X = f\ (KPVT)$$

where:

X = wear depth, mm

P = pressure, MPa

Operating limits

The wear rate of unlubricated SP21 operating in air is directly proportional to pressure and velocity if the surface temperature does not exceed 395°C (see Fig. 37). The proportionality factor (which we call the wear factor) is unaffected by large changes in operating conditions as long as the temperature does not exceed this critical value, called the wear transition temperature. Below the transition temperature, wear will be mild. However, the wear factor increases as soon as the temperature exceeds 395°C and becomes very large at about 540°C. Above 540°C, the SP will no longer support a load without yielding. However, if this high temperature excursion is short, the SP component will function normally after the temperature is reduced to a compatible

level. This decrease in wear resistance occuring at elevated temperatures is related to the thermal stability of the polyimide, so we expect the wear transition temperature will increase to 540°C in an inert or vacuum environment.

Figure 38 shows the pressure-velocity curve for a 395°C surface temperature for a SP21 thrust bearing operating in air at 23°C against mild steel. Note that the PV limit varies from 1 MPa · m/s at 0,07 MPa to 12 MPa · m/s at 7 MPa.
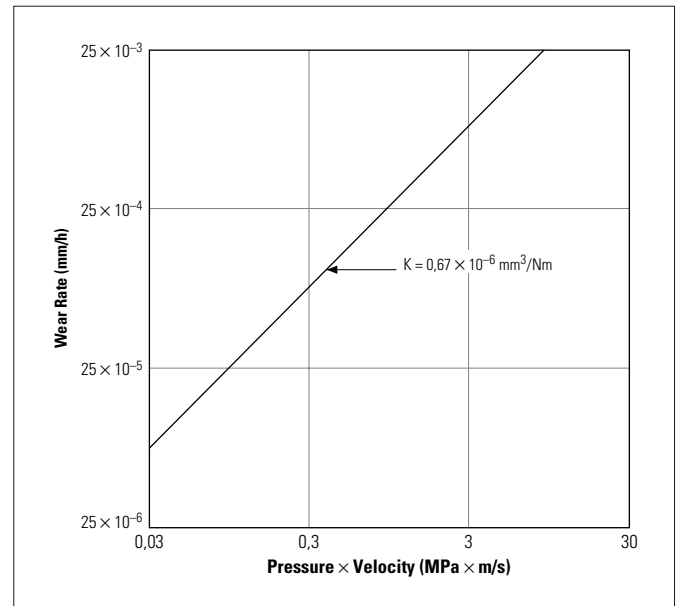
Fig. 37 **Wear rate vs. Pressure × Velocity for SP21 vs. carbon steel. Thrust bearing tester – no lubrication**

P = 0,07-22 MPa

V = 0,025-5,0 m/s

Surface temperature below 395°C
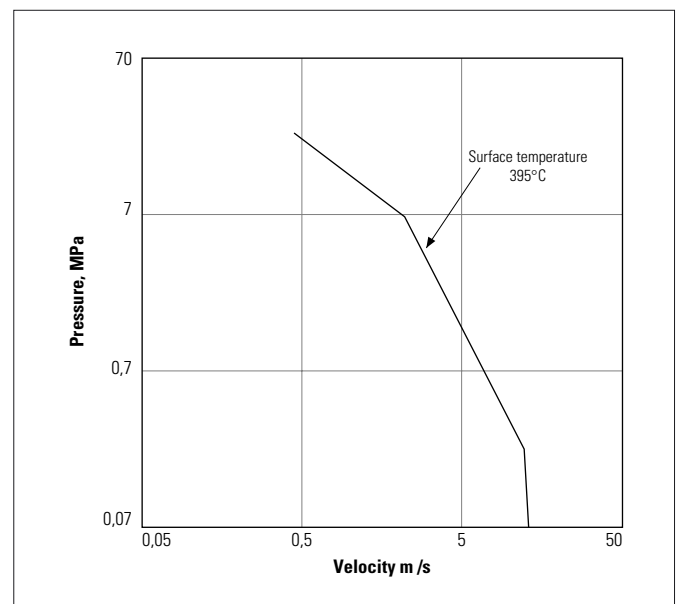
Fig. 38 **PV-limit of SP21 on thrust bearing tester vs. carbon steel – no lubrication**

Frictional behaviour

Temperature, pressure and velocity all affect the dynamic coefficient of friction. Typical coefficients of friction for various polyimide compositions are shown in Table 7 below.

The coefficients of friction for filled compositions undergo a transition at about 150°C, as shown in figure 39. Below this temperature the frictional behaviour is similar to that of 66 nylon, but above 150°C the frictional forces drop sharply, and in the range of 200 to 540°C, the friction characteristics of compositions remain independant of temperature. The friction transition is not associated with wear transition. The magnitude of the transition, and the wear rate below 150°C, are greatly reduced in SP211 (fig. 40).

The designer must allow for the higher frictional forces, resulting from two separate phenomena, which may be present during start-up. One is the transfer of a layer of polyimide resin/filler composition to the mating surface and the second is the temperature transition for polyimide resins. During restart, it may not be necessary under service conditions to break in a new layer, but the temperature effect is reversible and will continue to operate at each restart.

**Table 7 Typical coefficients of friction –
Unlubricated thrust bearing test**

Measurement		Composition		
Conditions	PV (MPa · m/s)	SP21	SP22	SP211
Static		0,30	0,27	0,20
P = 0,34 MPa V = 2,54 m/s	0,86	0,24	0,20	0,12
P = 0,69 MPa V = 0,51 m/s	0,35	0,35	–	0,24
P = 0,69 MPa V = 1,52 m/s	1,05	0,17	0,21	–
P = 0,69 MPa V = 5,08 m/s	3,5	0,07	0,09	0,08
P = 6,90 MPa V = 1,6 m/s	11	0,04	–	–
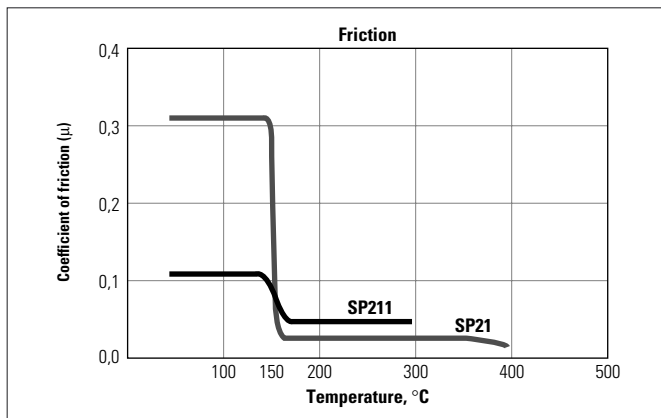
Fig. 39 **Coefficient of friction of SP21 and SP211 for unlubricated operation against mild carbon steel**
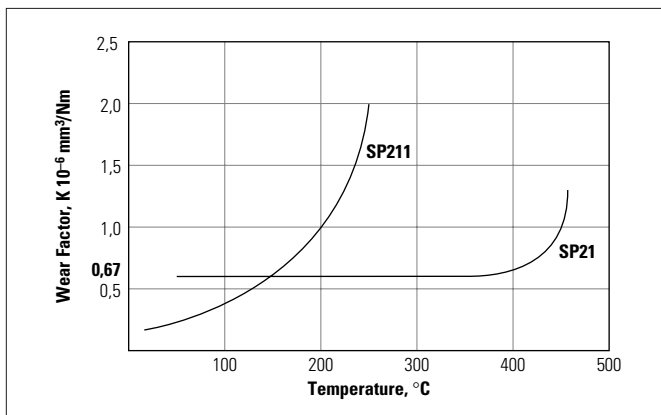
Fig. 40 **Wear factor of SP21 and SP211 for unlubricated operation against mild carbon steel**

Mating material and surface finish

The wear performance of VESPEL® parts can be substantially affected by the hardness of the mating material and its surface finish. Unlubricated bearing wear rates can be reduced by increasing the hardness and decreasing the roughness of the mating surface. In general, a ground surface finish on the mating material is prefereable to a turned surface. A fine polishing operation is often beneficial. The finishing operation should be in the same direction as the bearing motion relative to the mating surface. DuPont recommends a surface finish of 0,4 µm (Ra) and a hardness of $R_c = 55$.

Steel and cast iron are generally very good mating materials for all VESPEL® grades.

Very good behaviour has been seen with 100 Cr-6 and 20 Mn Cr-5 materials in bearings and transmission applications.

Aluminium and zinc are not good mating surfaces for plastic bearings because the softness of these materials can lead to rapid wear. If used, aluminium should be hardened or, preferably, anodized.

Die-cast aluminium with high silica content is very abrasive to VESPEL®.

A new polyimide composition, SP221, has recently been developped for applications in contact with soft metals like bronze or aluminium, in dry working conditions.
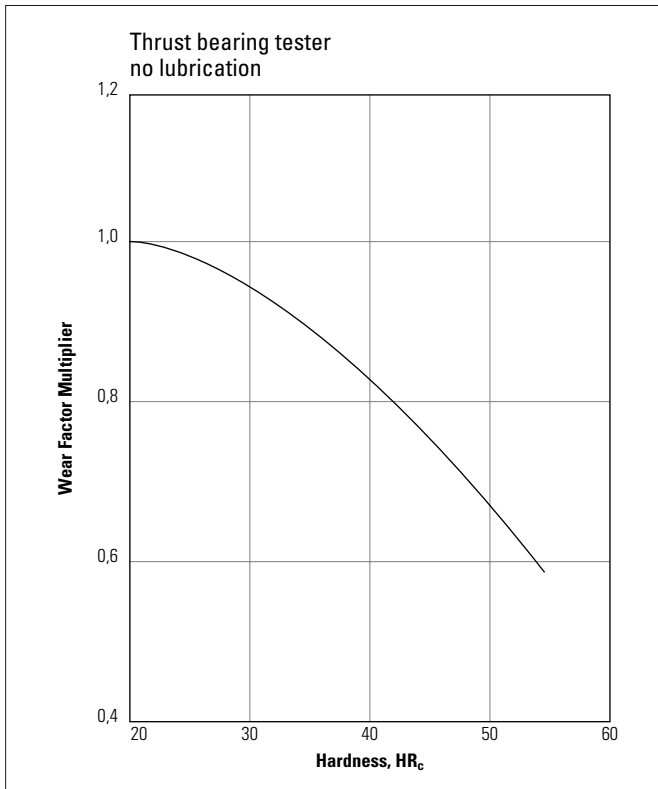
Fig. 41 **Effect of mating material hardness on wear**
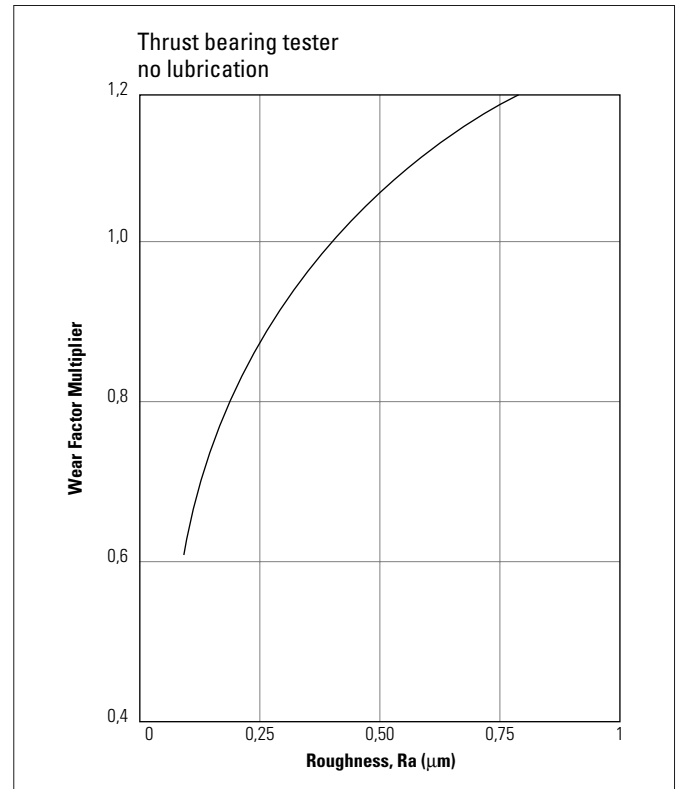
Fig. 42 **Effect of mating material surface finish on wear**

Figures 41 and 42 illustrate the effects of mating material hardness and finish on wear performance.

Plastic is not a good material for VESPEL® bearings and, if used, should be limited to low PV conditions. The softness of a plastic mating surface can lead to high wear. In addition, since plastics are relatively poor thermal conductors, plastic-to-plastic bearing interfaces run hotter than plastic-to-metal interfaces, so metal-plastic bearing systems have higher PV limits than plastic-plastic bearing systems.

Lubrication and other bearing design considerations

When determining whether bearings need to be lubricated, the following points should be considered:

- A one-time lubrication, consisting of an initial greasing or use of dry lubricant, generally reduces break-in wear and improves overall wear resistance.
- Lubrication of bearings can increase the PV limit by reducing coefficient of friction and helping to remove wear debris. Circulation of the lubricant can further increase the PV limit by cooling the bearing.
- Lubrication with a chemically compatible fluid to wet VESPEL® bearings will reduce both friction and wear rates. The amount of reduction increases with increasing fluid film thickness, which in turn increases with fluid viscosity and surface velocity, and decreases with increasing bearing pressure. Application geometry will also affect the reduction of friction. Even thin film lubricants can reduce dry wear rates by a factor of 10 or more. Thick films, which cause complete separation of the solid mating surfaces, can theoretically reduce wear to negligible proportions.

- The frictional behaviour of a bearing system using thin film lubrication is determined by the properties of the bearing material as well as by the properties of the lubricant. Frictional behaviour is determined exclusively by the lubricant properties with thick film lubrication.

Table 8 Coefficient of thermal expansion αSP

Composition	SP1		SP21	
Fabrication process	Mach.	Direct formed	Mach.	Direct formed
αSP 10⁻⁶ m/m/°C	54	50	49	41

SP22		SP211		ST2010	ST2030
Mach.	Direct formed	Mach.	Direct formed	Direct formed	Direct formed
38	27	54	41	48	32

- Unlubricated bearings should have surface grooves to carry wear debris out of the interface. In lubricated systems the grooves can help increase the supply of lubricant. The effect of grooving on bearing pressure should be considered.

- Because it does not wet SP resin, water is not an effective thin film or boundary lubricant for VESPEL® bearings. In fact, water can adversely affect the wear rate of dry VESPEL® bearings. However, periodic contamination by casual water should not cause any problems.

- Purging an unlubricated VESPEL® bearing with nitrogen gas can reduce wear rates to less than 20% of the corresponding rate in air. In addition, operation in nitrogen can increase the wear transition temperature by at least 50°C above the value in air.

- For applications in dirty environments, sealing or purging should be considered for prevention of bearing surface contamination.

Proportions

Journal bearings: For optimum performance of VESPEL® journal bearings, *l*/d (length/diameter) ratios in the order of $1/2$ to $3/2$ are suggested. If a long bearing is required, consider using two bearings with a gap between them. Smaller values of *l*/d will result in:
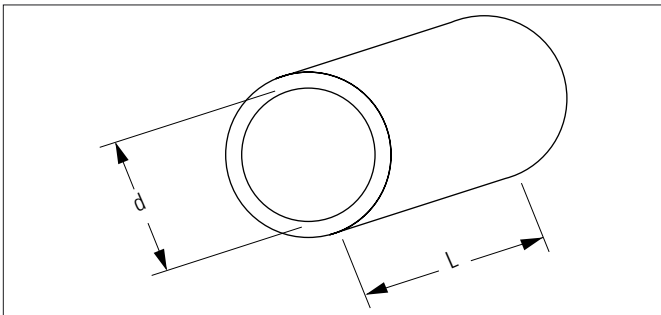
- more efficient debris removal;
- less sensitivity to shaft deflection and misalignment;
- better heat dissipation;
- cost advantages due to lower fabrication costs.

Thrust bearings: For optimum performance of VESPEL® thrust bearings, it is best not to exceed a ratio of outside to inside diameter (D/d) of 2. Ratios greater than 2 can cause overheating at the outside edge, and problems may arise from lack of flatness and from trapped wear debris.
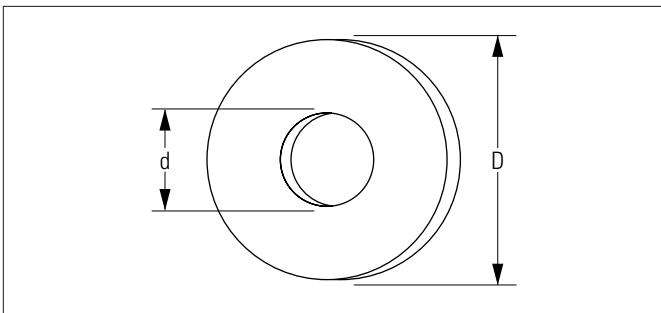
Running clearances for Journal bearings

Although VESPEL® bearings have much lower coefficients of thermal expansion than most plastics, minimal running clearances are required. Normal operating clearances for VESPEL® journal bearings are from 0,3% to 0,5% of shaft diameter, depending on the application. In general, heavier loads require larger clearances. Closer running clearances can be engineered by slotting the bearing to allow for circumferenctial thermal expansion.

To calculate the VESPEL® bearing design inside diameter it is important to estimate the actual temperature on the shaft and the VESPEL® bearing surface. The heat created by friction has to be added to the ambient temperature. In a broad range of applications the thermal expansion of the housing is negligible, but can be considered for high ambient temperatures.

The following formula to determine the VESPEL® bearing design inside diameter should be used as a guideline. For more accurate calculations please contact your local DuPont VESPEL® representative. (See table 8 for VESPEL® coefficients of thermal expansion).

Bearing design ID = shaft diameter at room temperature + change in shaft diameter due to temperature change + operating clearance of shaft + change in the bearing wall thickness due to temperature.

$$ID = D (1 + \alpha S \Delta T_1 + C) + 2t\alpha SP\Delta T_2$$

where:
- D = shaft diameter at ambient temperature
- C = shaft operating clearance, per cent of shaft diameter
- αS = coefficient of expansion of shaft material
- αSP = coefficient of thermal expansion of VESPEL® bearing
- t = VESPEL® bearing wall thickness
- ΔT_1 = temperature rise for the shaft
- ΔT_2 = temperature rise for the bearing

Running clearances for VESPEL® bearings usually do not have to be adjusted for moisture, because polyimides absorb very little moisture. See figures 23 to 25, for moisture absorption curves.

Of course, PV limits and maximum use temperatures of any material will vary from application to application depending upon a number of different factors. Thorough application testing should be performed to determine how VESPEL® parts will perform in your application.

Wall thickness for journal bearings

VESPEL® journal bearing walls should be as thin as possible, because thin walls:
- improve dissipation of frictional heat;
- reduce running clearance variations resulting from thermal- and moisture-related dimensional changes;
- reduce distorsion under high loading.

For most applications, the typical wall thickness for VESPEL® bearings ranges from 1 to 2,5 mm.

Installation of journal bearings

VESPEL® journal bearings can be installed either mechanically or with adhesive.

To press-fit VESPEL® bearings into metal, the suggested practice is to use a low-interference fit. After it is pressed into place, the bore of the bearing will be reduced by 90 to 110% (depending on wall thickness, diameter and interference) of the calculated diametrical interference, which will result in a small compressive load in the bearing wall. A typical interference fit is 0,5%, but press-fit interference should be adjusted to the needs of the application. For more acurate calculations contact your local DuPont VESPEL® representative.

VESPEL® parts can be used with most commercial adhesives. The "Bonding Chapter" discusses selection of adhesives, surface preparation and other considerations. With any adhesive, it is important to follow the manufacturer's recommendations for best results.

Sample design problem

VESPEL® bearings are being considered for a blender dryer with the following requirements:

- Two bearings on a 38 mm shaft must support 17800 N, at temperatures ranging from 21°C to 274°C.
- Maximum bearing length is 38 mm and maximum allowable running clearance hot or cold is 0,40 mm.
- To prevent product contamination, the bearings cannot be lubricated and they must operate without service 40 hours per week for 3 years.
- The blender-dryer shaft rotates intermittently, 5% on, 95% off, at 20 rpm.

Will VESPEL® bearings meet these reequirements? Refer to the table "PV limit guidelines".

Solution

1. Check temperature limit

Limiting surface temperature of SP21 polyimide in air is 393°C, so unless PV is very high, the surface temperature should rise less than the 119°C difference between 274 and 393°C.

2. Check PV

Calculate bearing pressure:

$$P = \frac{F}{LD} = \frac{8900 \text{ N (per bearing)}}{38 \text{ mm} \times 38 \text{ mm}} = 6{,}163 \text{ MPa}.$$

Calculate shaft speed:

$$V = \pi \cdot DN = \frac{\pi \times 0{,}038 \text{ m} \times 20 \text{ rpm}}{60} = 0{,}04 \text{ m/s}$$

Calculate PV:

$$PV = 6{,}163 \text{ MPa} \times 0{,}04 \text{ m/s} = 0{,}245 \text{ MPa} \cdot \text{m/s}$$

At this low PV, SP21 polyimide will operate in its mild wear regime, so PV will not limit, especially considering the intermittent operation.

3. Check wear resistance

Calculate running time:

$$T = 0{,}05 \times \frac{40 \text{ hours}}{\text{week}} \times \frac{52 \text{ weeks}}{\text{year}} \times 3 \text{ years} = 312 \text{ hours}$$

$$\text{Radial wear} = \text{wear factor*} \times PV \times \text{running time} = 0{,}67 \times 10^{-6} \text{ mm}^3/\text{Nm} \times 0{,}245 \text{ MPa} \cdot \text{m/s} \times 1123200 \text{ s} = 0{,}183 \text{ mm}$$

* assumed to be $0{,}67 \cdot 10^{-6} \text{ mm}^3/\text{Nm}$ in that case.

This wear is less than the maximum allowable operating clearance. If the difference is enough to accommodate thermal expansion, then VESPEL® parts will meet the requirements.

4. Design-determine room temperature clearance

At this point, experience and judgement play a big role, and one can only approximate a solution. Experience dictates that the shaft, bearing surface, bearing OD and housing will all reach different operating temperatures.

Assume that:

- the contact surface reaches 56°C higher than the dryer temperature, but:
- the bearing body average temperature is only 28°C higher than the dryer, while:
- the housing remains at room temperature and restrains the bearing securely, so:
- the bearing will expand inward when the temperature rises, and
- the shaft will expand outward.

With these assumptions, initial room temperature clearance, Cd, can be determined with the following equation:

$$Cd = D\,(\alpha S \Delta T_1 + C) + 2\,t\alpha SP \Delta T_2$$

where:

D = shaft diameter

αS = coefficient of thermal expansion for shaft = $11 \times 10^{-6} \text{ m/m/°C}$

C = operating clearance, here 0,1%

t = bearing wall thickness

αSP = coefficient of thermal expansion for SP21 bearing = $41 \times 10^{-6} \text{ m/m/°C}$

ΔT_1 = temperature rise for shaft

ΔT_2 = temperature rise for bearing

If one picks a wall thickness of 1,59 mm

$$C_d = 38\,[11 \times 10^{-6} \cdot (330 - 21) + 0{,}001] + (2 \times 1{,}59 \times 41 \times 10^{-6}) \times (302 - 21) = 0{,}167 \text{ mm} + 0{,}037 \text{ mm} = 0{,}204 \text{ mm}$$

5. Check maximum clearance

Initial clearance plus wear after 3 years will then be

$$0{,}204 + 0{,}183 = 0{,}387 \text{ mm}$$

which is below the stated requirements.

Thus, VESPEL® bearings do meet the requirements to operate without lubrication in this elevated temperature situation.

If you encounter expansion problems, slot the bearing.

Lubricated bearings

VESPEL® parts also perform well lubricated. With full hydrodynamic lubrication (thick film), normal mechanical wear is absent and VESPEL® parts will perform as well as any conventional bearing material. With boundary layer (thin film) lubrication the wear (and friction) characteristics of SP are modified by the lubricant. The combination of partial separation and chemical modification of the surfaces influences the performance. Lubricant dynamic viscosity (Z), revolutions (N), and contact surface pressure (P) determine the lubricant film thickness which in turn determines the effectiveness of a VESPEL® bearing.

The wear factor of an SP21 plane thrust bearing operating with thin film lubrication drops rapidly with increasing ZN/P (the non-dimensional parameter controlling film thickness). See Figure 43 to compare lubricated performance of SP21, bronze and babbitt. The SP21 wear factor for all but the thinnest films is $0{,}2$-$0{,}4 \times 10^{-7}$, which is substantially better than the bronze and approximately equivalent to the babbitt for most film thicknesses.

However, SP outperforms both of these conventional materials when films are thin (ZN/P <3). Unfortunately, we do not understand enough about solid-liquid interactions to predict reliably the wear under all thin film conditions.

The coefficient of friction vs. ZN/P for all three materials is plotted in Figures 44, 45 and 46. Again SP shows its superiority; thinner films are required to reduce the friction forces. These results (as were the wear factors) were determined for a three segment plane thrust bearing lubricated with a non-additive petroleum oil with contact pressure ranging up to 13,8 MPa and sliding velocities ranging from 0,015 m/s to 15 m/s. The transition from thin film to thick film lubrication occurs at about the same film thickness for all materials and the hydrodynamic friction coefficients are the same.
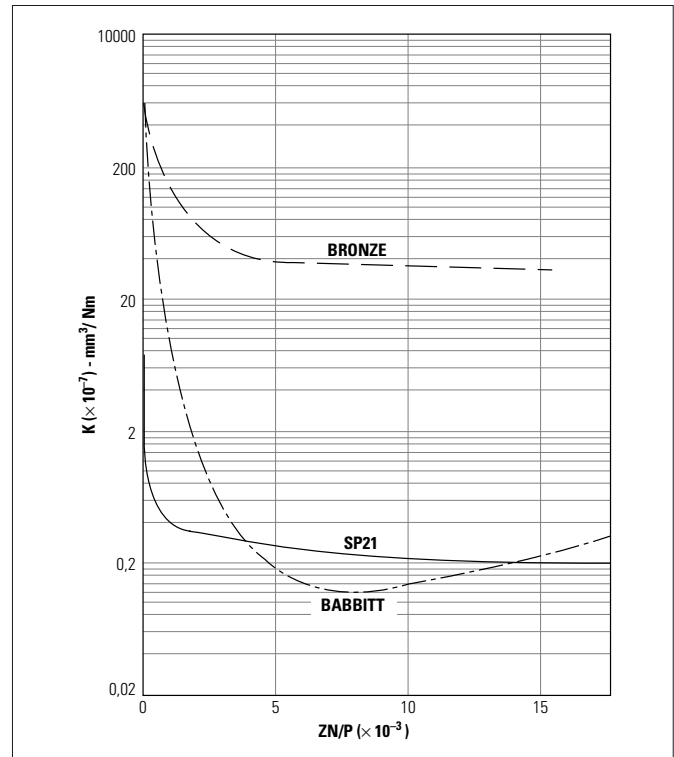
Fig. 43 **Lubricated wear test results. Wear factor vs ZN/P – Mating surface (AISI 1080, HR$_c$ = 55, Ra = 0,4). Segmented plane thrust bearing. "Sunvis" 31 Oil**
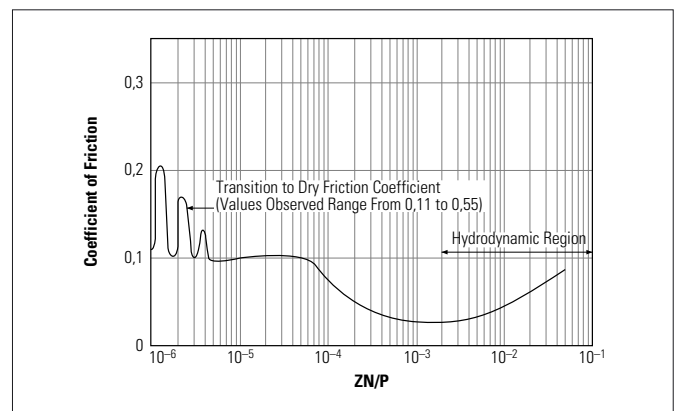
Fig. 44 **Lubricated friction test results. SP21 vs steel (AISI 1080, HR$_c$ = 55, Ra = 0,4). Segmented plane thrust bearing. "Sunvis" 31 Oil**
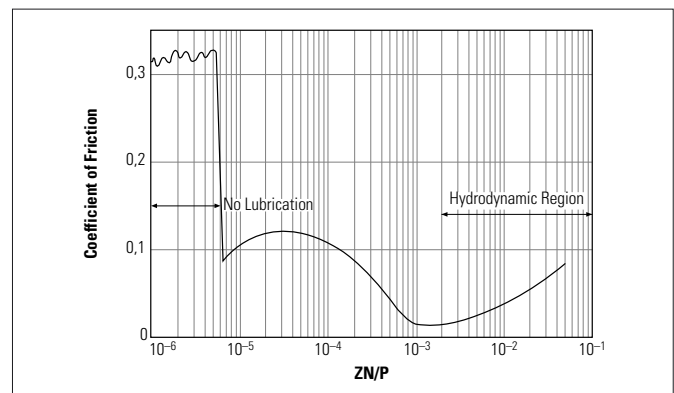
Fig. 45 **Lubricated friction test results. Bronze vs steel (AISI 1080, HR$_c$ = 23, Ra = 0,4). Segmented plane thrust bearing. "Sunvis" 31 Oil**
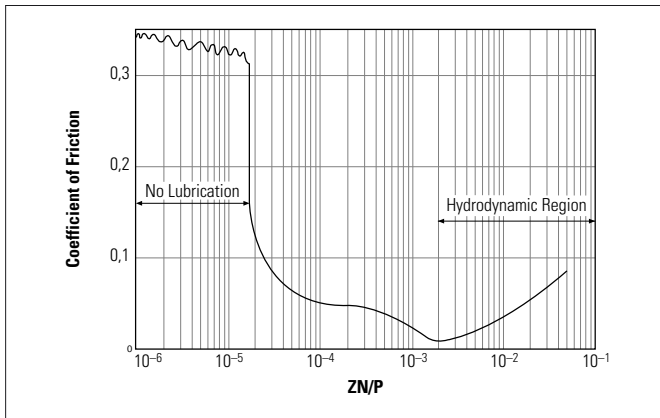
Fig. 46 **Lubricated friction test results. Babbitt vs steel (AISI 1080, HR$_c$ = 23, Ra = 0,4). Segmented plane thrust bearing. "Sunvis" 31 Oil**

Lubrication failure

An important factor to consider if lubricant starvation can occur in one of your systems is the unlubricated performance of the bearing. While neither bronze nor babbitt will operate without lubrication, VESPEL® parts will perform without galling or failing as long as the temperature limit is not exceeded. Thus, if the lubricant supply is shut off, the wear and friction characteristics will merely shift from the boundary layer regime to the unlubricated regime. The superiority of polyimide material in this situation is clearly shown in Figure 47. As the lubricant benefits are lost, the friction forces for all three systems quickly rise. However, both of the conventional bearing materials fail while the VESPEL® bearing operates without interruption.

SP21 thrust bearings have performed well in type "A" transmission fluid and F-50 silicone fluid. However, thin film of some fluids, such as water, do not lubricate well. The fluid must wet the sliding surfaces to be effective. For instance, a water film thick enough to provide sufficient surface separation actually increases the wear rate of polyimide parts. This effect is not unusual; it has occurred with other plastics. The general solution is to add a surfactant to reduce the fluid surface tension.

Stick-Slip effect

This term describes a splutter movement at start-up when changing from adhesion to sliding. It appears predominantly at extreme small velocities and increased sliding rate. Frequently it is a result of a surface smothing of the metal counterpart.

Through decrease of the surface load, utilisation of a rougher metal surface, or hardening of it, as well as lubricating, this effect may often be overcome.

Fig. 47 **Lubricant starvation test – Segmented plane thrust bearing. Mating surface: AISI 1080. Surface finish: HR$_c$ = 55, Ra = 0,4. P = 3,5 MPa – V = 0,1 m/s. "Sunvis" 31 Oil – ZN/P ≈ 1,4 × 10^{-4} at T = 0**

41

Seal ring

Why polyimides?

For high temperature applications requiring flexibility and superior sealing compliance, polyimide plastics boost seal ring performance. Polyimides operate continuously from cryogenic temperatures to 300°C, with short-term use to 500°C, and can carry loads at temperatures beyond the reach of other plastics. They are far more compliant than metals, but because of their resiliency resist permanent deformation.

Polyimides offer the best structural features of cast iron – a common seal ring material – and engineering plastics, including low wear and low friction characteristics, coupled with greater stability than most other plastics. An important difference between polyimides and other seal ring materials is performance in unlubricated environments, such as gas sealing applications. Because of their inherent lubricity, polyimides provide outstanding wear resistance in unlubricated environments, with dry pressure velocity limits up to 12 MPa m/s.

Polyimides stand up to most industrial fluids, solvents, hydrocarbons and synthetic lubricants (hydraulic oil, transmission fluid), inert gases (such as nitrogen and argon) and certain fuels. Because of this, polyimide seal rings are well suited for transmissions, pneumatic and hydraulic cylinders, off-road vehicles, military equipment and valve applications.

Using VESPEL® parts in your application can result in reduced warranty costs, less machine down time, and lower manufacturing cost.

This chapter helps you to use VESPEL® seal rings in the most economical and efficient way. Inside you will find:
* A guide to parameters important in seal ring design;
* Methods for designing VESPEL® seal rings;
* Proposals on getting the maximum performance from VESPEL®;
* Recommended tolerances for VESPEL® seal rings.

More detailed information about VESPEL® seal rings can be found in the "Automotive VESPEL®" brochure reference H-11198 and in the SAE paper 980734 "Improving Automatic Transmission Quality with High Performance Polyimide Rotary Seal Rings".

Glossary of design parameters

All seal ring applications share certain geometric parameters, as shown in these two illustrations.
* **Bore** – the inner diameter of the cylindrical space within which the seal ring is constrained to move.
* **Nominal diameter** – outer diameter of the seal ring. Usually equals the bore.
* **Gauge diameter** – Diameter of the mesauring device, usually ~0,2 mm above nominal diameter.

* **Radial thickness** – the difference between inner and outer diameters of the seal ring, sometimes referred to as "wall thickness".
* **Axial thickness** – thickness of the seal ring from top to bottom (ring height).
* **Gap** – distance between the open ends of the seal ring when constrained at the gauge diameter.
* **Nominal gap** – distance between the open ends of the seal ring when constrained at the nominal diameter.
* **Groove root** – the diameter of the groove which will face the inner surface of the seal ring.
* **Groove width** – axial dimension of the seal ring groove.
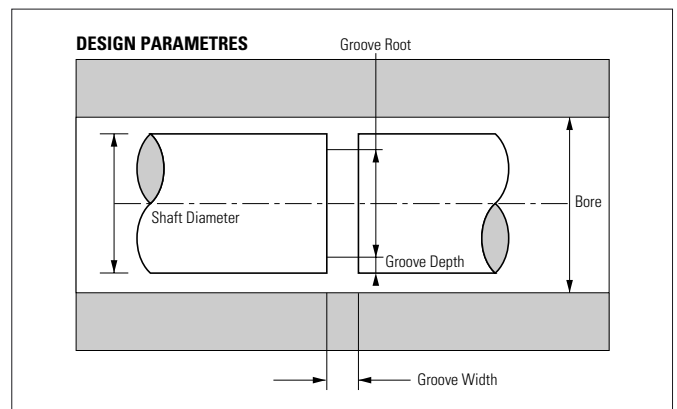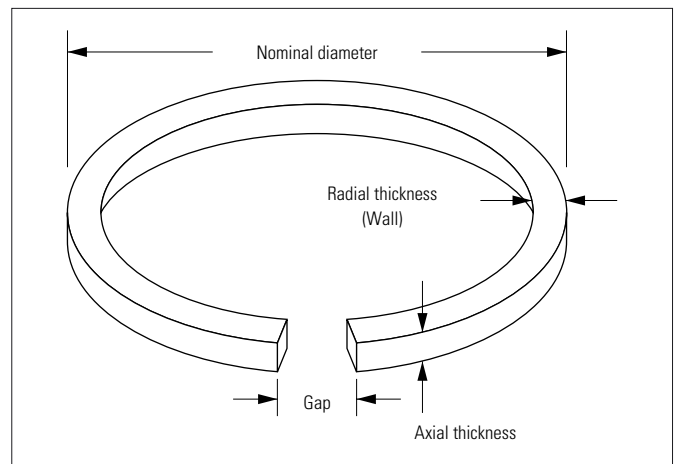
Standard design direct formed butt joint seal rings

If you have an existing application which uses a seal ring made from metals or from other engineering plastics, several factors should be considered when specifying new VESPEL® seal rings. The following guidelines specify the relationships between dimensions of the existing system and the size of the replacement ring. All dimensions are given in mm.

1. Nominal diameter
The outer diameter of the expanded seal ring should be equal to the bore diameter in the system.

2. (Axial thickness)$_{max}$ = (GROOVE WIDTH)$_{min}$ – 0,1 mm

Allow a total of 0,1 mm lateral clearance for the seal ring in the ring groove at maximum temperature.

3. (RADIAL THICKNESS)$_{max}$ = 0,5 [(BORE)$_{min}$ – (GROOVE ROOT DIAMETER)$_{max}$] – 0,1 mm

Allow a total of 0,1 mm radial clearance between bore and root at maximum temperature.

4. (GAP)$_{min}$ = $\pi \times$ (GAGE DIAMETER) (T_{max} – 20) (αSP – αB)

where

T = temperature, °C

αB = thermal coefficient of expansion of bore material, 10^{-6} 1/°C

αSP = thermal coefficient of expansion of VESPEL® part, 10^{-6} 1/°C (see Table 8).

This equation calculates the minimum gap required accounting for thermal expansion of the seal ring at operating temperature. Ring will just close at calculated temperature.
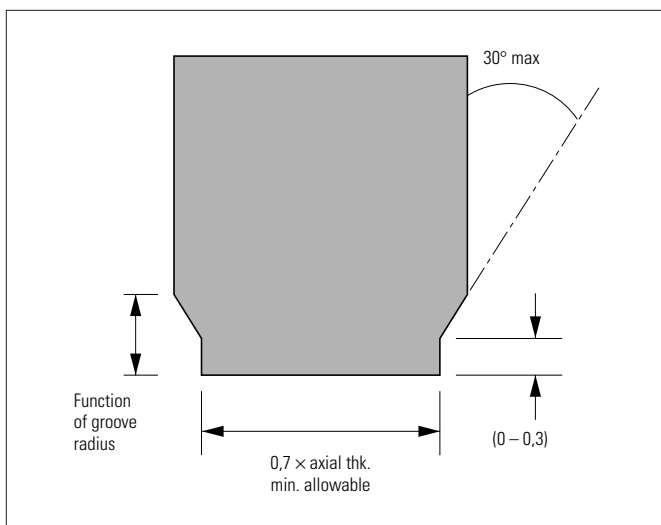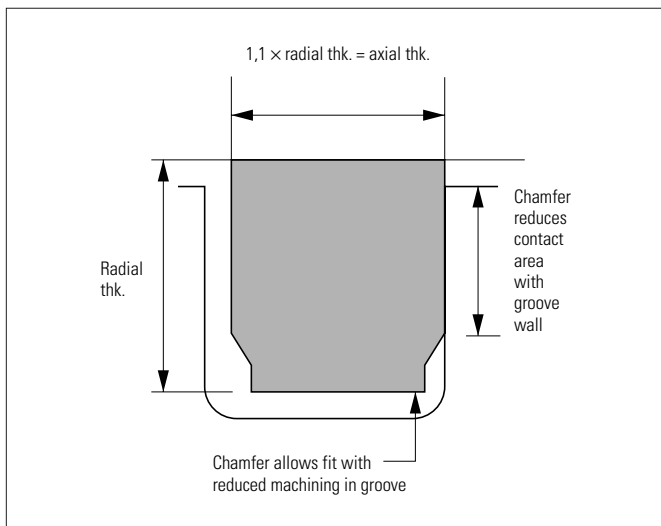
5. (AXIAL THICKNESS) $\geq$ 1,1 (RADIAL THICKNESS)

VESPEL® seal rings may be chamfered at the inside diameter to reduce contact between the ring and groove faces if the geometry of the assembly results in an axial thickness less than 1,1 times the radial thickness. Radial thickness is reduced by the chamfer length, creating a better pressure balance to hold the ring against the bore. Another advantage of the chamfer is that it allows clearance with any groove root radii present from the groove machining operator.
The chamfer should be tapered no greater than 30° and have a 0–0,3 mm shoulder, below the chamfer. The thickness at the shoulder (i.e. at the thinnest part of the ring) should be no greater than 70% of axial thickness.

Other design considerations

• **Groove surface finish** – Surface finish of the metal is an important factor in the design of seal ring systems, because of the abrasive action between mating materials. VESPEL® parts perform extremely well, especially under lubricated conditions. A smooth surface finish of 0,4 μm Ra is recommended. The mating material of the ring groove should be as hard as possible. If cast iron is used, however, surface finish is less crucial. Field tests demonstrate that cast iron mating surfaces with a finish of 2,0 μm Ra wear as well as those ground to 0,8 μm Ra finish.
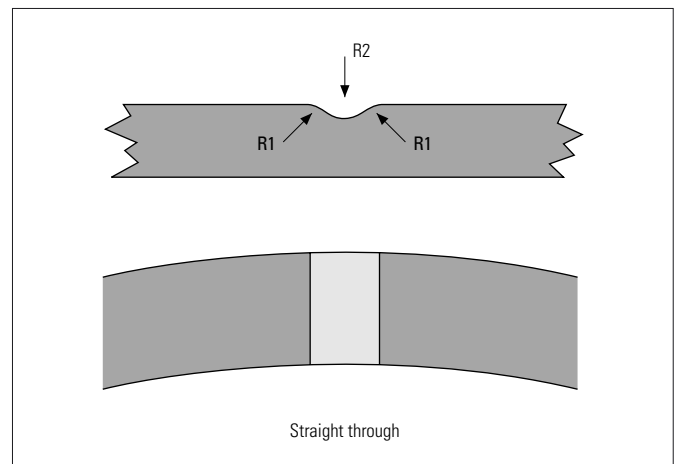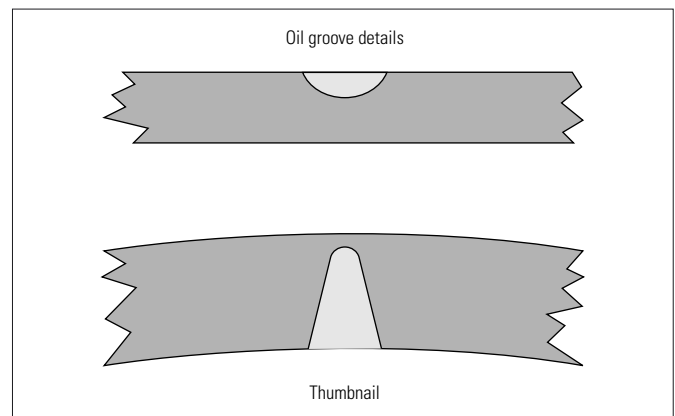
- **Measuring ring gaps** – Most plastics will absorb moisture to some extent when held in air. Because the moisture content will affect the dimensions of the ring, gaps are measured only after the ring has been dried for 3 hours at 150°C. This simulates the condition of the ring during actual use, and ensures that all moisture has been eliminated. VESPEL® rings can only be measured accurately when placed in a gauge and expanded to the outside of the gauge. Optical methods are required.

- **Oil grooves** – Grooves designed to carry lubricant to the face of the ring will improve wear characteristics of the ring. VESPEL® seal rings can be optionally supplied with a number of oil groove configurations. The two designs shown here have been tested in a broad variety of applications and have proved successful in numerous cases.

Design tolerances

Designing seal rings with polyimides calls for a new approach to tolerances. Their superior compliance and low-friction surfaces allow designers to create seal rings that do not need the tight tolerances necessary with metals. In fact, polyimide rings provide better sealing compliance than metal-to-metal seals machined to much tighter tolerances.

This helps designers cut costs by reducing expensive surface finishing and machining operations. The Table below gives tolerance guidelines for standard polyimide seal rings.

Another benefit of the material's excellent compliance occurs during system assembly. Because polyimides offer more stability than other engineering plastics but more flexibility than metals, they hold up better during assembly, and are often easier to install.

Cast iron seal rings are hard but brittle, and often break during assembly. Seal rings made from other engineering plastics, because they are softer than polyimides, will often shear or cut during assembly without detection.

TYPICAL SEAL RING DESIGN

SECTION L – L

GROOVE DETAIL

SECTION B – B

Tolerance guidelines (Dimensions given in mm)

Gauge diameter	Gap	Axial wall	Radial wall
<38	±0,10	±0,10	±0,025
38 to 64	±0,125	±0,125	±0,025
64 to 89	±0,15	±0,15	±0,040
89 to 127	±0,175	±0,175	±0,040
127 to 178	±0,23	±0,23	±0,050
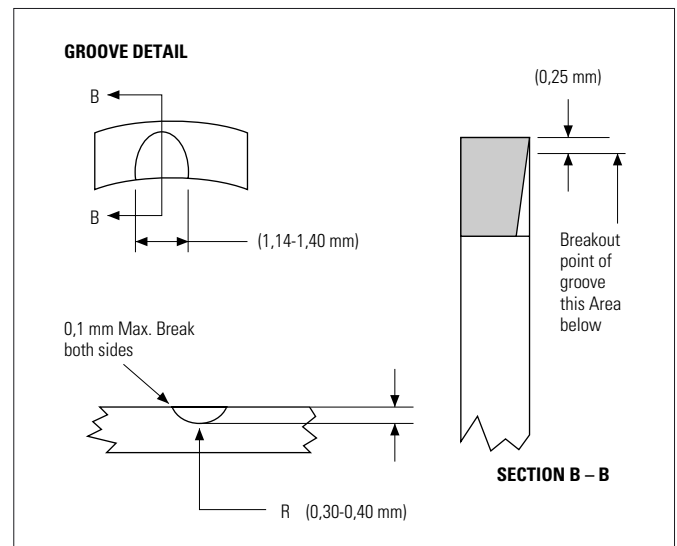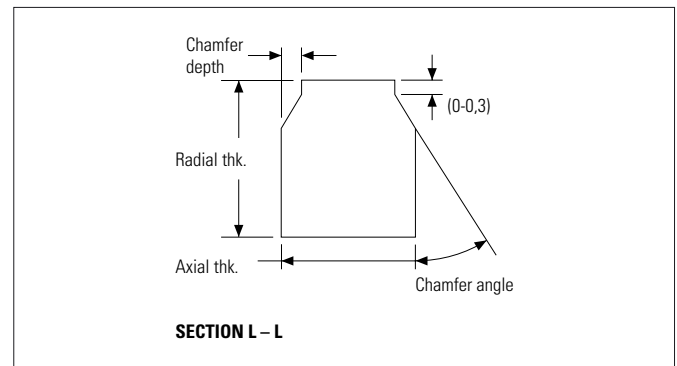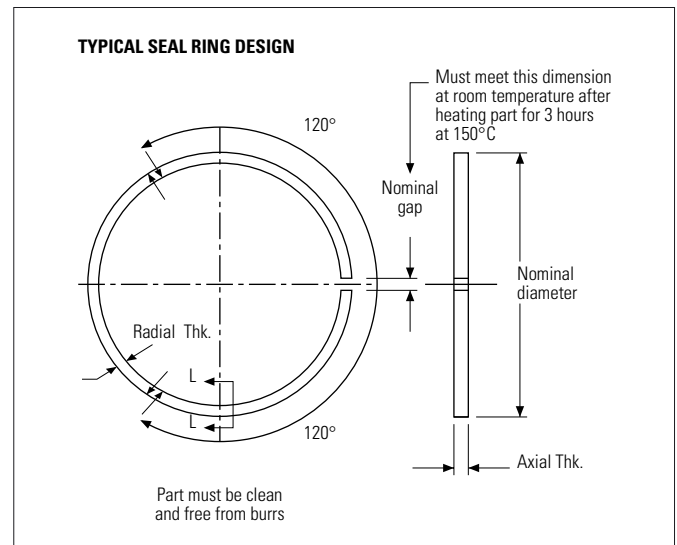
VESPEL® grades for seal rings

SP21 is the standard material for seal rings chosen because it offers the best combination of mechanical strength and wear resistance.

SP22 provides approximately the same wear characteristics but is more brittle. The linear thermal expansion however is lower than SP21.

SP211 is similar to SP21 but offers a lower coefficient of friction up to 150°C.

Due to the influence of the manufacturing process on the coefficient of thermal expansion (see Table 8) customer testing should be done with parts machined out of the material (Direct Formed or Stock Shapes) which will be used later on in the end-use application.

Aluminium mating surface

Contrary to most other seal rings VESPEL® may run either against the groove side wall or the bore. When one material is aluminium and the other one steel/cast iron it is beneficial to design the ring in a way that the relative movement takes place between VESPEL® and steel/cast iron.

Special designed seal rings

More and more special requirements on seal rings, especially in automotive automatic transmissions, have lead to a variety of different guidelines to design seal rings according to specific needs.

Gap geometry

Butt joint   • Direct formable
                  • Gap will close over temperature and can take compression without permanent deformation
                  • Cost-effective solution
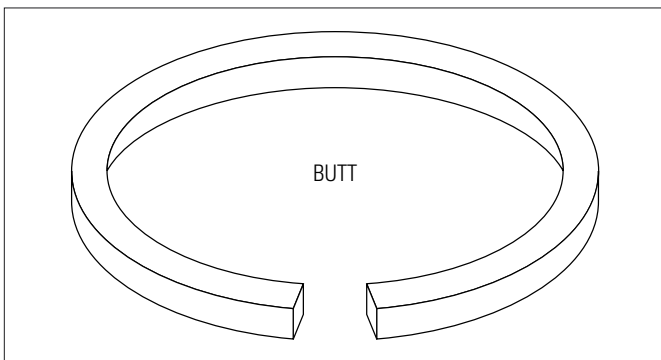
Scarf joint   • Not direct formable
                  • Has to be cut
                  • Gap closing effect over temperature is much smaller than the butt joint gap.
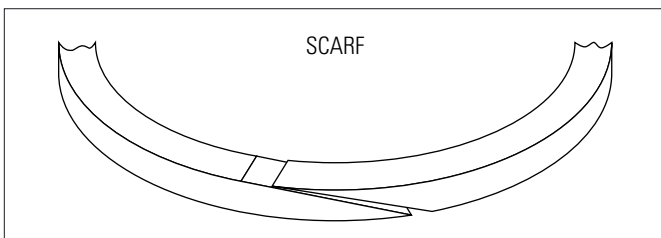
Stepped joint   • Can be direct formed depending on geometry
                  • Behaves in principle like a butt joint with a slightly reduced clearance
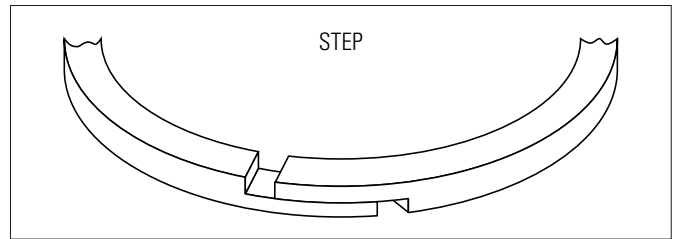
Very low leak rates with compressed butt joint seal rings

As VESPEL® is a tough material it can take some compression without permanent deformation. Therefore a VESPEL® butt joint seal ring can be designed to have a closed ("0") gap from 20°C up to maximum operating temperature. The thermal expansion of the VESPEL® ring will be taken by the inherent elastic deformation rate of the material. A minimum oil pressure is needed to press the ring against the sealing surface to overcome the warped shape of the ring in the groove when under thermal compression. The needed minimum oil pressure increases with smaller diameters. Therefore, it is very important to know the minimum pressure of this sealing system.

For these very low constant leakrate rings, the axial thickness should be as large as groove and design guidelines permit. It is recommended that the relative movement of the seal ring should take place between itself and the shaft groove, i.e. the seal ring is almost stationary relative to the housing.

Scarf joint seal rings

Scarf joint seal rings with a cut of usually 20° are very widely used and well known. These rings cannot be produced in one step; the cut has to be machined after the full ring has been pressed.

The leak rate for scarf joint seal rings is somewhat higher than that for compressed butt joint rings. However, scarf joint rings are not as sensitive to the minimum pressure of the transmission.

Assembly

VESPEL® rings can be produced to have a memory that forces the rings to the groove root. These rings will be delivered closed or overlapped at the gap. Once these rings are assembled on to the shaft, they tend to stay to the inside of the groove root. This effect allows easy and safe assembly into the housing, without using grease.

It is recommended nevertheless to keep the rings packed till the final assembly and to use conical tools to smoothly guide the seal rings in their respective grooves. Contact your local VESPEL® sales representative for more details and advices.

VESPEL® rings have a higher flexural modulus than for example PTFE rings and can therefore be used in automated assembly production lines.

The maximum wall thickness for compressed rings has to be:

$0,5 \times$ (DIAM. SHAFT$_{min}$ – GROOVE ROOT DIAM$_{max}$) $-0,05$ mm

In order to avoid breakage of the seal ring during shaft assembly into the housing, the tolerance on the wall thickness has to be as small as possible.

Selection

The grade selection should take into account the difference in thermal expansion and wear rates of the various proposed grades. The seal ring gap type and gap tolerances are specified on the basis of the operating conditions, leakage requirements and minimum pressure of the transmission. Figures 48 to 51 show the influence of seal ring gap type and material grade on leak rates.
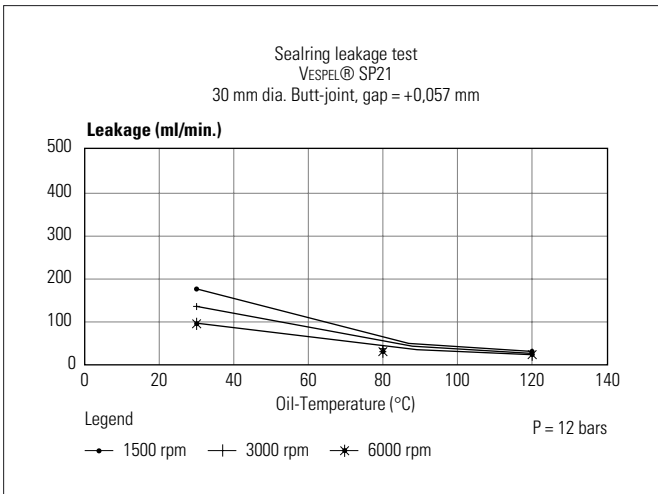
Fig. 48   **SP21 Seal ring. Butt joint gap (positive)**
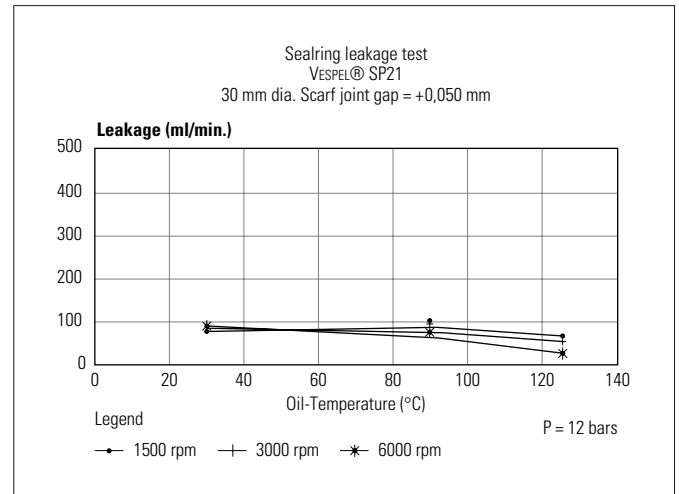
Fig. 50   **SP21 Seal ring. Scarf joint gap**
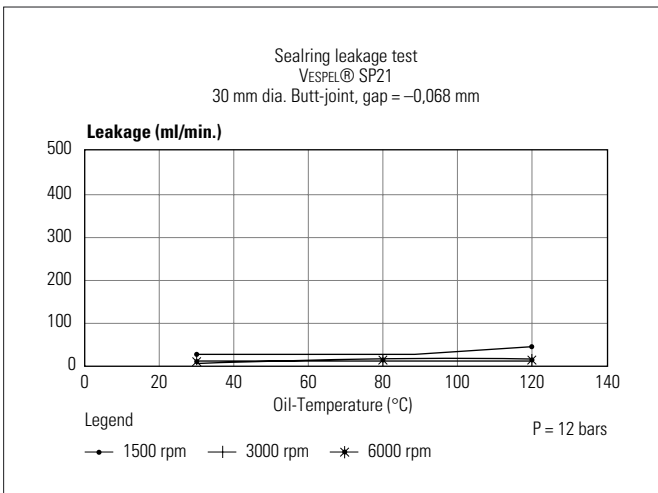
Fig. 49   **SP21 Seal ring. Butt joint gap compressed (negative)**

Fig. 51   **SP22 Seal ring. Scarf joint gap**

Tables and figures

Appendix A

Standard shapes dimensions

Rods

Minimum Diameter mm	Length mm
6,3	965
9,5	965
11,1	965
12,7	965
15,8	965
19,0	965
25,4	965
31,7	965
38,1	965
50,8	965
63,5	965
82,5	685

Plaques

Minimum Thickness mm	Surface
50,8	
38,1	254×254 mm^2
25,4	254×127 mm^2
12,7	127×127 mm^2
6,3	
4,8*	
3,2*	
1,6*	

* Thin plaques are only available in SP1 and SP21 with a surface of 254×254 mm^2.

Bars

Minimum cross-sectional dimensions Width $\times$ thickness mm	Maximum length
$101 \times 50,8$ mm	965 mm / 317,5 mm

Rings and discs

A variety of rings and discs are offered in diameters ranging from 15,8 mm to 63,5 mm with thicknesses of 3,1 mm to 6,3 mm.

Balls only in SP1

Diameter in mm
3,2
6,3
9,5
12,7
15,8

Ball diameter tolerances are $\pm$ 0,051 mm.

Tubes

Diameter Minimum OD mm	Maximum ID mm	Maximum Length mm
180	142	838
170	142	838
162	142	838
170	119	838
149	119	838
142	119	838
165	109	838
154	109	838
144	109	838
137	109	838
121	109	838
137	86,3	838
124	86,3	838
109	86,3	838
94	86,3	838
129	66,0	838
119	66,0	838
101	66,0	838
86,3	66,0	838
124	48,2	838
111	48,2	838
94,0	48,2	838
78,7	48,2	838
43,1	35,5	685
40,6	27,9	685

Most outside dimensions listed above are minimum dimensions. Actual inside diameter of tubes are slightly smaller than shown.

Appendix B ISO Tolerances

AXLES

Lowest and highest dimensional deviation in μ (0,001 mm)

Nominal dimensions in mm above	till	g5	h5	j5	k5	m5	n5	g6	h6	j6	k6	m6	n6	r6	f7	h7	j7	k7	m7	n7	b8	e8	f8	h8	d9	e9	f9	h9	d10	a11	b11	c11	d11	h11
–	1	-2/-6	0/-4	+2/-2	+4/0	+6/+2	+8/+4	-2/-8	0/-6	+4/-2	+6/0	+8/+2	+10/+4	+16/+10	-6/-16	0/-10	+6/-4	+10/0	–	+14/+4	–	-14/-28	-6/-20	0/-14	-20/-45	-14/-39	-6/-31	0/-25	-20/-60	–	–	-60/-120	-20/-80	0/-60
1	3	-2/-6	0/-4	+2/-2	+4/0	+6/+2	+8/+4	-2/-8	0/-6	+4/-2	+6/0	+8/+2	+10/+4	+16/+10	-6/-16	0/-10	+6/-4	+10/0	–	+14/+4	-140/-154	-14/-28	-6/-20	0/-14	-20/-45	-14/-39	-6/-31	0/-25	-20/-60	-270/-330	-140/-200	-60/-120	-20/-80	0/-60
3	6	-4/-9	0/-5	+3/-2	+6/+1	+9/+4	+13/+8	-4/-12	0/-8	+6/-2	+9/+1	+12/+4	+16/+8	+23/+15	-10/-22	0/-12	+8/-4	+13/+1	+16/+4	+20/+8	-140/-158	-20/-38	-10/-28	0/-18	-30/-60	-20/-50	-10/-40	0/-30	-30/-78	-270/-345	-140/-215	-70/-145	-30/-105	0/-75
6	10	-5/-11	0/-6	+4/-2	+7/+1	+12/+6	+16/+10	-5/-14	0/-9	+7/-2	+10/+1	+15/+6	+19/+10	+28/+19	-13/-28	0/-15	+10/-5	+16/+1	+21/+6	+25/+10	-150/-172	-25/-47	-13/-35	0/-22	-40/-76	-25/-61	-13/-49	0/-36	-40/-98	-280/-370	-150/-240	-80/-170	-40/-130	0/-90
10	14	-6/-14	0/-8	+5/-3	+9/+1	+15/+7	+20/+12	-6/-17	0/-11	+8/-3	+12/+1	+18/+7	+23/+12	+34/+23	-16/-34	0/-18	+12/-6	+19/+1	+25/+7	+30/+12	-150/-177	-32/-59	-16/-43	0/-27	-50/-93	-32/-75	-16/-59	0/-43	-50/-120	-290/-400	-150/-260	-95/-205	-50/-160	0/-110
14	18	-6/-14	0/-8	+5/-3	+9/+1	+15/+7	+20/+12	-6/-17	0/-11	+8/-3	+12/+1	+18/+7	+23/+12	+34/+23	-16/-34	0/-18	+12/-6	+19/+1	+25/+7	+30/+12	-150/-177	-32/-59	-16/-43	0/-27	-50/-93	-32/-75	-16/-59	0/-43	-50/-120	-290/-400	-150/-260	-95/-205	-50/-160	0/-110
18	24	-7/-16	0/-9	+5/-4	+11/+2	+17/+8	+24/+15	-7/-20	0/-13	+9/-4	+15/+2	+21/+8	+28/+15	+41/+28	-20/-41	0/-21	+13/-8	+23/+2	+29/+8	+36/+15	-160/-193	-40/-73	-20/-53	0/-33	-65/-117	-40/-92	-20/-72	0/-52	-65/-149	-300/-430	-160/-290	-110/-240	-65/-195	0/-130
24	30	-7/-16	0/-9	+5/-4	+11/+2	+17/+8	+24/+15	-7/-20	0/-13	+9/-4	+15/+2	+21/+8	+28/+15	+41/+28	-20/-41	0/-21	+13/-8	+23/+2	+29/+8	+36/+15	-160/-193	-40/-73	-20/-53	0/-33	-65/-117	-40/-92	-20/-72	0/-52	-65/-149	-300/-430	-160/-290	-110/-240	-65/-195	0/-130
30	40	-9/-20	0/-11	+6/-5	+13/+2	+20/+9	+28/+17	-9/-25	0/-16	+11/-5	+18/+2	+25/+9	+33/+17	+50/+34	-25/-50	0/-25	+15/-10	+27/+2	+34/+9	+42/+17	-170/-209	-50/-89	-25/-64	0/-39	-80/-142	-50/-112	-25/-87	0/-62	-80/-180	-310/-470	-170/-330	-120/-280	-80/-240	0/-160
40	50	-9/-20	0/-11	+6/-5	+13/+2	+20/+9	+28/+17	-9/-25	0/-16	+11/-5	+18/+2	+25/+9	+33/+17	+50/+34	-25/-50	0/-25	+15/-10	+27/+2	+34/+9	+42/+17	-180/-219	-50/-89	-25/-64	0/-39	-80/-142	-50/-112	-25/-87	0/-62	-80/-180	-320/-480	-180/-340	-130/-290	-80/-240	0/-160
50	65	-10/-23	0/-13	+6/-7	+15/+2	+24/+11	+33/+20	-10/-29	0/-19	+12/-7	+21/+2	+30/+11	+39/+20	+60/+41	-30/-60	0/-30	+18/-12	+32/+2	+41/+11	+50/+20	-190/-236	-60/-106	-30/-76	0/-46	-100/-174	-60/-134	-30/-104	0/-74	-100/-220	-340/-530	-190/-380	-140/-330	-100/-290	0/-190
65	80	-10/-23	0/-13	+6/-7	+15/+2	+24/+11	+33/+20	-10/-29	0/-19	+12/-7	+21/+2	+30/+11	+39/+20	+62/+43	-30/-60	0/-30	+18/-12	+32/+2	+41/+11	+50/+20	-200/-246	-60/-106	-30/-76	0/-46	-100/-174	-60/-134	-30/-104	0/-74	-100/-220	-360/-550	-200/-390	-150/-340	-100/-290	0/-190
80	100	-12/-27	0/-15	+6/-9	+18/+3	+28/+13	+38/+23	-12/-34	0/-22	+13/-9	+25/+3	+35/+13	+45/+23	+73/+51	-36/-71	0/-35	+20/-15	+38/+3	+48/+13	+58/+23	-220/-274	-72/-126	-36/-90	0/-54	-120/-207	-72/-159	-36/-123	0/-87	-120/-260	-380/-600	-220/-440	-170/-390	-120/-340	0/-220
100	120	-12/-27	0/-15	+6/-9	+18/+3	+28/+13	+38/+23	-12/-34	0/-22	+13/-9	+25/+3	+35/+13	+45/+23	+76/+54	-36/-71	0/-35	+20/-15	+38/+3	+48/+13	+58/+23	-240/-294	-72/-126	-36/-90	0/-54	-120/-207	-72/-159	-36/-123	0/-87	-120/-260	-410/-630	-240/-460	-180/-400	-120/-340	0/-220
120	140	-14/-32	0/-18	+7/-11	+21/+3	+33/+15	+45/+27	-14/-39	0/-25	+14/-11	+28/+3	+40/+15	+52/+27	+88/+63	-43/-83	0/-40	+22/-18	+43/+3	+55/+15	+67/+27	-260/-323	-85/-148	-43/-106	0/-63	-145/-245	-85/-185	-43/-143	0/-100	-145/-305	-460/-710	-260/-510	-200/-450	-145/-395	0/-250
140	160	-14/-32	0/-18	+7/-11	+21/+3	+33/+15	+45/+27	-14/-39	0/-25	+14/-11	+28/+3	+40/+15	+52/+27	+90/+65	-43/-83	0/-40	+22/-18	+43/+3	+55/+15	+67/+27	-280/-343	-85/-148	-43/-106	0/-63	-145/-245	-85/-185	-43/-143	0/-100	-145/-305	-520/-770	-280/-530	-210/-460	-145/-395	0/-250
160	180	-14/-32	0/-18	+7/-11	+21/+3	+33/+15	+45/+27	-14/-39	0/-25	+14/-11	+28/+3	+40/+15	+52/+27	+93/+68	-43/-83	0/-40	+22/-18	+43/+3	+55/+15	+67/+27	-310/-373	-85/-148	-43/-106	0/-63	-145/-245	-85/-185	-43/-143	0/-100	-145/-305	-580/-830	-310/-560	-230/-480	-145/-395	0/-250
180	200	-15/-35	0/-20	+7/-13	+24/+4	+37/+17	+51/+31	-15/-44	0/-29	+16/-13	+33/+4	+46/+17	+60/+31	+106/+77	-50/-96	0/-46	+25/-21	+50/+4	+63/+17	+77/+31	-340/-412	-100/-172	-50/-122	0/-72	-170/-285	-100/-215	-50/-165	0/-115	-170/-355	-660/-950	-340/-630	-240/-530	-170/-460	0/-290
200	225	-15/-35	0/-20	+7/-13	+24/+4	+37/+17	+51/+31	-15/-44	0/-29	+16/-13	+33/+4	+46/+17	+60/+31	+109/+80	-50/-96	0/-46	+25/-21	+50/+4	+63/+17	+77/+31	-380/-452	-100/-172	-50/-122	0/-72	-170/-285	-100/-215	-50/-165	0/-115	-170/-355	-740/-1030	-380/-670	-260/-550	-170/-460	0/-290
225	250	-15/-35	0/-20	+7/-13	+24/+4	+37/+17	+51/+31	-15/-44	0/-29	+16/-13	+33/+4	+46/+17	+60/+31	+113/+84	-50/-96	0/-46	+25/-21	+50/+4	+63/+17	+77/+31	-420/-492	-100/-172	-50/-122	0/-72	-170/-285	-100/-215	-50/-165	0/-115	-170/-355	-820/-1110	-420/-710	-280/-570	-170/-460	0/-290
250	280	-17/-40	0/-23	+7/-16	+27/+4	+43/+20	+57/+34	-17/-49	0/-32	+16/-16	+36/+4	+52/+20	+66/+34	+126/+94	-56/-108	0/-52	+26/-26	+56/+4	+72/+20	+86/+34	-480/-561	-110/-191	-56/-137	0/-81	-190/-320	-110/-240	-56/-186	0/-130	-190/-400	-920/-1240	-480/-800	-300/-620	-190/-510	0/-320
280	315	-17/-40	0/-23	+7/-16	+27/+4	+43/+20	+57/+34	-17/-49	0/-32	+16/-16	+36/+4	+52/+20	+66/+34	+130/+98	-56/-108	0/-52	+26/-26	+56/+4	+72/+20	+86/+34	-540/-621	-110/-191	-56/-137	0/-81	-190/-320	-110/-240	-56/-186	0/-130	-190/-400	-1050/-1370	-540/-860	-330/-650	-190/-510	0/-320
315	355	-18/-43	0/-25	+7/-18	+29/+4	+46/+21	+62/+37	-18/-54	0/-36	+18/-18	+40/+4	+57/+21	+73/+37	+144/+108	-62/-119	0/-57	+29/-28	+61/+4	+78/+21	+94/+37	-600/-689	-125/-214	-62/-151	0/-89	-210/-350	-125/-265	-62/-202	0/-140	-210/-440	-1200/-1560	-600/-960	-360/-720	-210/-570	0/-360
355	400	-18/-43	0/-25	+7/-18	+29/+4	+46/+21	+62/+37	-18/-54	0/-36	+18/-18	+40/+4	+57/+21	+73/+37	+150/+114	-62/-119	0/-57	+29/-28	+61/+4	+78/+21	+94/+37	-680/-769	-125/-214	-62/-151	0/-89	-210/-350	-125/-265	-62/-202	0/-140	-210/-440	-1350/-1710	-680/-1040	-400/-760	-210/-570	0/-360
400	450	-20/-47	0/-27	+7/-20	+32/+5	+50/+23	+67/+40	-20/-60	0/-40	+20/-20	+45/+5	+63/+23	+80/+40	+166/+126	-68/-131	0/-63	+31/-32	+68/+5	+86/+23	+103/+40	-760/-857	-135/-232	-68/-165	0/-97	-230/-385	-135/-290	-68/-223	0/-155	-230/-480	-1500/-1900	-760/-1160	-440/-840	-230/-630	0/-400
450	500	-20/-47	0/-27	+7/-20	+32/+5	+50/+23	+67/+40	-20/-60	0/-40	+20/-20	+45/+5	+63/+23	+80/+40	+172/+132	-68/-131	0/-63	+31/-32	+68/+5	+86/+23	+103/+40	-840/-937	-135/-232	-68/-165	0/-97	-230/-385	-135/-290	-68/-223	0/-155	-230/-480	-1650/-2050	-840/-1240	-480/-880	-230/-630	0/-400

Lowest and highest dimensional deviation in µ (0,001 mm)

HOLES

Nominal dimensions in mm (above)	(till)	G6	H6	J6	K6	M6	N6	F7	G7	H7	J7	K7	M7	N7	R7	B8	E8	F8	H8	J8	K8	M8	N8	D9	E9	D10	A11	B11	C11	D11	H11
–	1	+8 / +2	+6 / 0	+2 / -4	0 / -6	-2 / -8	-4 / -10	+16 / +6	+12 / +2	+10 / 0	+4 / -6	0 / -10	-2 / -12	-4 / -14	-10 / -20	–	+28 / +14	+20 / +6	+14 / 0	+6 / -8	0 / -14	–	-4 / -18	+45 / +20	+39 / +14	+60 / +20	–	–	+120 / +60	+80 / +20	+60 / 0
1	3	+8 / +2	+6 / 0	+2 / -4	0 / -6	-2 / -8	-4 / -10	+16 / +6	+12 / +2	+10 / 0	+4 / -6	0 / -10	-2 / -12	-4 / -14	-10 / -20	+154 / +140	+28 / +14	+20 / +6	+14 / 0	+6 / -8	0 / -14	–	-4 / -18	+45 / +20	+39 / +14	+60 / +20	+330 / +270	+200 / +140	+120 / +60	+80 / +20	+60 / 0
3	6	+12 / +4	+8 / 0	+5 / -3	+2 / -6	-1 / -9	-5 / -13	+22 / +10	+16 / +4	+12 / 0	+6 / -6	+3 / -9	0 / -12	-4 / -16	-11 / -23	+158 / +140	+38 / +20	+28 / +10	+18 / 0	+10 / -8	+5 / -13	+2 / -16	-2 / -20	+60 / +30	+50 / +20	+78 / +30	+345 / +270	+215 / +140	+145 / +70	+105 / +30	+75 / 0
6	10	+14 / +5	+9 / 0	+5 / -4	+2 / -7	-3 / -12	-7 / -16	+28 / +13	+20 / +5	+15 / 0	+8 / -7	+5 / -10	0 / -15	-4 / -19	-13 / -28	+172 / +150	+47 / +25	+35 / +13	+22 / 0	+12 / -10	+6 / -16	+1 / -21	-3 / -25	+76 / +40	+61 / +25	+98 / +40	+370 / +280	+240 / +150	+170 / +80	+130 / +40	+90 / 0
10	14	+17 / +6	+11 / 0	+6 / -5	+2 / -9	-4 / -15	-9 / -20	+34 / +16	+24 / +6	+18 / 0	+10 / -8	+6 / -12	0 / -18	-5 / -23	-16 / -34	+177 / +150	+59 / +32	+43 / +16	+27 / 0	+15 / -12	+8 / -19	+2 / -25	-3 / -30	+93 / +50	+75 / +32	+120 / +50	+400 / +290	+260 / +150	+205 / +95	+160 / +50	+110 / 0
14	18	+17 / +6	+11 / 0	+6 / -5	+2 / -9	-4 / -15	-9 / -20	+34 / +16	+24 / +6	+18 / 0	+10 / -8	+6 / -12	0 / -18	-5 / -23	-16 / -34	+177 / +150	+59 / +32	+43 / +16	+27 / 0	+15 / -12	+8 / -19	+2 / -25	-3 / -30	+93 / +50	+75 / +32	+120 / +50	+400 / +290	+260 / +150	+205 / +95	+160 / +50	+110 / 0
18	24	+20 / +7	+13 / 0	+8 / -5	+2 / -11	-4 / -17	-11 / -24	+41 / +20	+28 / +7	+21 / 0	+12 / -9	+6 / -15	0 / -21	-7 / -28	-20 / -41	+193 / +160	+73 / +40	+53 / +20	+33 / 0	+20 / -13	+10 / -23	+4 / -29	-3 / -36	+117 / +65	+92 / +40	+149 / +65	+430 / +300	+290 / +160	+240 / +110	+195 / +65	+130 / 0
24	30	+20 / +7	+13 / 0	+8 / -5	+2 / -11	-4 / -17	-11 / -24	+41 / +20	+28 / +7	+21 / 0	+12 / -9	+6 / -15	0 / -21	-7 / -28	-20 / -41	+193 / +160	+73 / +40	+53 / +20	+33 / 0	+20 / -13	+10 / -23	+4 / -29	-3 / -36	+117 / +65	+92 / +40	+149 / +65	+430 / +300	+290 / +160	+240 / +110	+195 / +65	+130 / 0
30	40	+25 / +9	+16 / 0	+10 / -6	+3 / -13	-4 / -20	-12 / -28	+50 / +25	+34 / +9	+25 / 0	+14 / -11	+7 / -18	0 / -25	-8 / -33	-25 / -50	+209 / +170	+89 / +50	+64 / +25	+39 / 0	+24 / -15	+12 / -27	+5 / -34	-3 / -42	+142 / +80	+112 / +50	+180 / +80	+470 / +310	+330 / +170	+280 / +120	+240 / +80	+160 / 0
40	50	+25 / +9	+16 / 0	+10 / -6	+3 / -13	-4 / -20	-12 / -28	+50 / +25	+34 / +9	+25 / 0	+14 / -11	+7 / -18	0 / -25	-8 / -33	-25 / -50	+219 / +180	+89 / +50	+64 / +25	+39 / 0	+24 / -15	+12 / -27	+5 / -34	-3 / -42	+142 / +80	+112 / +50	+180 / +80	+480 / +320	+340 / +180	+290 / +130	+240 / +80	+160 / 0
50	65	+29 / +10	+19 / 0	+13 / -6	+4 / -15	-5 / -24	-14 / -33	+60 / +30	+40 / +10	+30 / 0	+18 / -12	+9 / -21	0 / -30	-9 / -39	-30 / -60	+236 / +190	+106 / +60	+76 / +30	+46 / 0	+28 / -18	+14 / -32	+5 / -41	-4 / -50	+174 / +100	+134 / +60	+220 / +100	+530 / +340	+380 / +190	+330 / +140	+290 / +100	+190 / 0
65	80	+29 / +10	+19 / 0	+13 / -6	+4 / -15	-5 / -24	-14 / -33	+60 / +30	+40 / +10	+30 / 0	+18 / -12	+9 / -21	0 / -30	-9 / -39	-32 / -62	+246 / +200	+106 / +60	+76 / +30	+46 / 0	+28 / -18	+14 / -32	+5 / -41	-4 / -50	+174 / +100	+134 / +60	+220 / +100	+550 / +360	+390 / +200	+340 / +150	+290 / +100	+190 / 0
80	100	+34 / +12	+22 / 0	+16 / -6	+4 / -18	-6 / -28	-16 / -38	+71 / +36	+47 / +12	+35 / 0	+22 / -13	+10 / -25	0 / -35	-10 / -45	-38 / -73	+274 / +220	+126 / +72	+90 / +36	+54 / 0	+34 / -20	+16 / -38	+6 / -48	-4 / -58	+207 / +120	+159 / +72	+260 / +120	+600 / +380	+440 / +220	+390 / +170	+340 / +120	+220 / 0
100	120	+34 / +12	+22 / 0	+16 / -6	+4 / -18	-6 / -28	-16 / -38	+71 / +36	+47 / +12	+35 / 0	+22 / -13	+10 / -25	0 / -35	-10 / -45	-41 / -76	+294 / +240	+126 / +72	+90 / +36	+54 / 0	+34 / -20	+16 / -38	+6 / -48	-4 / -58	+207 / +120	+159 / +72	+260 / +120	+630 / +410	+460 / +240	+400 / +180	+340 / +120	+220 / 0
120	140	+39 / +14	+25 / 0	+18 / -7	+4 / -21	-8 / -33	-20 / -45	+83 / +43	+54 / +14	+40 / 0	+26 / -14	+12 / -28	0 / -40	-12 / -52	-48 / -88	+323 / +260	+148 / +85	+106 / +43	+63 / 0	+41 / -22	+20 / -43	+8 / -55	-4 / -67	+245 / +145	+185 / +85	+305 / +145	+710 / +460	+510 / +260	+450 / +200	+395 / +145	+250 / 0
140	160	+39 / +14	+25 / 0	+18 / -7	+4 / -21	-8 / -33	-20 / -45	+83 / +43	+54 / +14	+40 / 0	+26 / -14	+12 / -28	0 / -40	-12 / -52	-50 / -90	+343 / +280	+148 / +85	+106 / +43	+63 / 0	+41 / -22	+20 / -43	+8 / -55	-4 / -67	+245 / +145	+185 / +85	+305 / +145	+770 / +520	+530 / +280	+460 / +210	+395 / +145	+250 / 0
160	180	+39 / +14	+25 / 0	+18 / -7	+4 / -21	-8 / -33	-20 / -45	+83 / +43	+54 / +14	+40 / 0	+26 / -14	+12 / -28	0 / -40	-12 / -52	-53 / -93	+373 / +310	+148 / +85	+106 / +43	+63 / 0	+41 / -22	+20 / -43	+8 / -55	-4 / -67	+245 / +145	+185 / +85	+305 / +145	+830 / +580	+560 / +310	+480 / +230	+395 / +145	+250 / 0
180	200	+44 / +15	+29 / 0	+22 / -7	+5 / -24	-8 / -37	-22 / -51	+96 / +50	+61 / +15	+46 / 0	+30 / -16	+13 / -33	0 / -46	-14 / -60	-60 / -106	+412 / +340	+172 / +100	+122 / +50	+72 / 0	+47 / -25	+22 / -50	+9 / -63	-5 / -77	+285 / +170	+215 / +100	+355 / +170	+950 / +660	+630 / +340	+530 / +240	+460 / +170	+290 / 0
200	225	+44 / +15	+29 / 0	+22 / -7	+5 / -24	-8 / -37	-22 / -51	+96 / +50	+61 / +15	+46 / 0	+30 / -16	+13 / -33	0 / -46	-14 / -60	-63 / -109	+452 / +380	+172 / +100	+122 / +50	+72 / 0	+47 / -25	+22 / -50	+9 / -63	-5 / -77	+285 / +170	+215 / +100	+355 / +170	+1030 / +740	+670 / +380	+550 / +260	+460 / +170	+290 / 0
225	250	+44 / +15	+29 / 0	+22 / -7	+5 / -24	-8 / -37	-22 / -51	+96 / +50	+61 / +15	+46 / 0	+30 / -16	+13 / -33	0 / -46	-14 / -60	-67 / -113	+492 / +420	+172 / +100	+122 / +50	+72 / 0	+47 / -25	+22 / -50	+9 / -63	-5 / -77	+285 / +170	+215 / +100	+355 / +170	+1110 / +820	+710 / +420	+570 / +280	+460 / +170	+290 / 0
250	280	+49 / +17	+32 / 0	+25 / -7	+5 / -27	-9 / -41	-25 / -57	+108 / +56	+69 / +17	+52 / 0	+36 / -16	+16 / -36	0 / -52	-14 / -66	-74 / -126	+561 / +480	+191 / +110	+137 / +56	+81 / 0	+55 / -26	+25 / -56	+9 / -72	-5 / -86	+320 / +190	+240 / +110	+400 / +190	+1240 / +920	+800 / +480	+620 / +300	+510 / +190	+320 / 0
280	315	+49 / +17	+32 / 0	+25 / -7	+5 / -27	-9 / -41	-25 / -57	+108 / +56	+69 / +17	+52 / 0	+36 / -16	+16 / -36	0 / -52	-14 / -66	-78 / -130	+621 / +540	+191 / +110	+137 / +56	+81 / 0	+55 / -26	+25 / -56	+9 / -72	-5 / -86	+320 / +190	+240 / +110	+400 / +190	+1370 / +1050	+860 / +540	+650 / +330	+510 / +190	+320 / 0
315	355	+54 / +18	+36 / 0	+29 / -7	+7 / -29	-10 / -46	-26 / -62	+119 / +62	+75 / +18	+57 / 0	+39 / -18	+17 / -40	0 / -57	-16 / -73	-87 / -144	+689 / +600	+214 / +125	+151 / +62	+89 / 0	+60 / -29	+28 / -61	+11 / -78	-5 / -94	+350 / +210	+265 / +125	+440 / +210	+1560 / +1200	+960 / +600	+720 / +360	+570 / +210	+360 / 0
355	400	+54 / +18	+36 / 0	+29 / -7	+7 / -29	-10 / -46	-26 / -62	+119 / +62	+75 / +18	+57 / 0	+39 / -18	+17 / -40	0 / -57	-16 / -73	-93 / -150	+769 / +680	+214 / +125	+151 / +62	+89 / 0	+60 / -29	+28 / -61	+11 / -78	-5 / -94	+350 / +210	+265 / +125	+440 / +210	+1710 / +1350	+1040 / +680	+760 / +400	+570 / +210	+360 / 0
400	450	+60 / +20	+40 / 0	+33 / -7	+8 / -32	-10 / -50	-27 / -67	+131 / +68	+83 / +20	+63 / 0	+43 / -20	+18 / -45	0 / -63	-17 / -80	-103 / -166	+857 / +760	+232 / +135	+165 / +68	+97 / 0	+66 / -31	+29 / -68	+11 / -86	-6 / -103	+385 / +230	+290 / +135	+480 / +230	+1900 / +1500	+1160 / +760	+840 / +440	+630 / +230	+400 / 0
450	500	+60 / +20	+40 / 0	+33 / -7	+8 / -32	-10 / -50	-27 / -67	+131 / +68	+83 / +20	+63 / 0	+43 / -20	+18 / -45	0 / -63	-17 / -80	-109 / -172	+937 / +840	+232 / +135	+165 / +68	+97 / 0	+66 / -31	+29 / -68	+11 / -86	-6 / -103	+385 / +230	+290 / +135	+480 / +230	+2050 / +1650	+1240 / +840	+880 / +480	+630 / +230	+400 / 0

Appendix C

Material safety data

VESPEL® POLYIMIDE PARTS AND SHAPES ALL IN SYNONYM LIST VSP001

Chemical product/Company identification

Material identification

VESPEL® is a registered trademark of DuPont
Corporate MSDS Number DU003855

Tradenames and Synonyms

VESPEL® SP1, SP3, SP21, SP22,
SP211, SP221,

VESPEL® SP1D, SP21D, SP22D,
SP211D, SP221D,

VESPEL® ST2000, ST2000D, ST2005, ST2005D,
ST2010, ST2010D, ST2030, ST2030D

Company Identification

Manufacturer/Distributor
DuPont
Polymers
1007 Market Street
Wilmington, DE 19898, U.S.A.

Phone numbers
Product information   1-800-441-7515
Transport emergency 1-800-424-9300
Medical emergency   1-800-441-3637

Composition/Information on ingredients

Components

Material	CAS No.	%
Poly-N,N'-(p,p'-oxydiphenylene) pyromellitimide	25038-81-7	50-100
Present in SP21, 22, 211, 221, and ST series only: Graphite (none in ST2000)	7782-42-5	2-40
Present in type SP3 only: Molybdenum disulphide	1317-33-5	15
in SP211, 221 (10-15%) and D-types (<1%) only: Polytetrafluoroethylene (PTFE)	9002-84-0	0,2-15

Remarks

Material is not known to contain Toxic Chemicals under Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.

Hazards identification

Additional health effects

VESPEL® polyimide parts and shapes are not hazardous as shipped.
For SP211, 221 and D-types, machining of parts may generate particles that contain polytetrafluoroethylene (PTFE). Machining with a dull tool and/or no coolant may cause temperatures to exceed 260°C. The primary hazard associated with PTFE is the inhalation of fumes from overheating (>260°C) or burning PTFE, which may cause "polymer fume fever", a temporary flu-like illness with fever, chills, and sometimes cough, of approximately 24 hours duration. Smokers should avoid contamination of tobacco products with this material. Small amounts of carbonyl fluoride and hydrogen fluoride may also be evolved when PTFE is overheated or burned.

Poly-N,N'-(p,p'-oxydiphenylene) pyromellitimide

The polymer resin is a slight skin irritant, but is not a skin sensitiser in animals. Effects of a single exposure by inhalation include discomfort and difficult respiration (4 hour LC50 is 15600 mg/m³ in rats). Effects of repeated oral exposure include reduced food consumption and reduced rate of weight gain.
Human health effects of overexposure by skin contact may include skin irritiation with discomfort or rash. Inhalation may cause irritation of the upper respiratory passages, with coughing and discomfort. No acceptable information is available to confidently predict the effects of excessive human exposure by eye contact, or ingestion. Significant skin permeation, and systemic toxicity, after contact appears unlikely. There are no reports of human sensitisation.

Graphite

Very low toxicity by ingestion (oral LD50 >5000 mg/kg in rats). The compound is not an eye irritant. Human health effects of overexposure by long term inhalation may include chronic lung disorders with symptoms of lung insufficiency. Individuals with preexisting diseases of the lungs may have increased susceptibility to the toxicity of excessive exposure to graphite.

Molybdenum disulfide

No acceptable information is available to confidently predict the effects of excessive human exposure to this compound.

Polytetrafluoroethylene (PTFE)

The compound is not a skin irritant. Effects in animals from single exposure by inhalation to high concentration of the dust include irritation of the lungs. Repeated oral doses resulted in no observable toxic effects except for alteration in the number of circulating white blood cells after long-term dosing (25% of diet for 90 days). Tests demonstrate no developmental toxicity in animals, and no genetic damage in animals or in bacterial cell cultures.

Human health effects of overexposure

Inhalation of fumes from overheating PTFE may cause polymer fume fever, a temporary flu-like illness with fever, chills, and sometimes cough, of approximately 24 hours duration. There are some reports in the literature of persistent pulmonary effects in individuals, especially smokers, who have had repeated episodes of polymer fume fever. Because of complicating factors, such as mixed exposures and smoking history, these findings are uncertain. Protection against acute exposure should also provide protection against any potential chronic effects. Smokers should avoid contamination of tobacco products, and should wash their hands before smoking. Significant skin permeation after contact appears unlikely. There are no reports of human sensitization. Small amounts of carbonyl fluoride and hydrogen fluoride may also be evolved when PTFE is overheated or burned.

Inhalation of low concentrations of *hydrogen fluoride* can initially include symptoms of choking, coughing, and severe eye, nose, and throat irritation. Possibly followed after a symptomless period of 1 to 2 days by fever, chills, difficulty in breathing, cyanosis, and pulmonary edema. Acute or chronic overexposure to HF can injure the liver and kidneys.

Inhalation, ingestion, or skin or eye contact with *carbonyl fluoride* may initially include: skin irritation with discomfort or rash; eye corrosion with corneal or conjunctival ulceration; irritation of the upper respiratory passages; or temporary lung irritation effects with cough, discomfort, difficulty breathing, or shortness of breath. Symptoms may be delayed.

Individuals with preexisting diseases of the lungs may have increased susceptibility to the toxicity of excessive exposures from thermal decomposition products.

Carcinogenicity information

None of the components present in this material at concentrations equal to or greated than 0,1% are listed by IARC, NTP, OSHA or ACGIH as a carcinogen.

First aid measures

First aid

Inhalation
No specific intervention is indicated as the compound is not likely to be hazardous by inhalation.
Consult a physician if necessary.

Skin contact
The compound is not likely to be hazardous by skin contact but cleansing the skin after use is advisable.

Eye contact
In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Call a physician.

Ingestion
No specific intervention is indicated as compound is not likely to be hazardous by ingestion.
Consult a physician if necessary.

Fire fighting measures

Flammable properties
Will not burn without external flame.

Fire and explosion hazards:
Hazardous gases/vapours produced in fire are: carbon monoxide, carbon dioxide, smoke. SP211, 221, and D-types may also produce hydrogen fluoride, carbonyl fluoride and low molecular weight fluorocarbons.

Extinguishing media
Use media appropriate for surrounding material.

Fire fighting instructions
Wear self-contained breathing apparatus. In a fire, SP211, 221 and D-types form hydrogen fluoride fumes which react with water to form hydrofluoric acid.
Wear *neoprene* gloves when handling refuse from a fire involving these types.

Accidental release measures

Safeguards (Personnel)
Note: Review *fire fighting measures and handling (personnel)* sections before proceeding with clean-up. Use appropriate personnel protective equipment during clean-up.

Spill clean up
Recover undamaged and minimally contaminated material for reuse and reclamation. Shovel or sweep up.

Handling and storage

Handling (Personnel)

Avoid contamination of cigarettes or tobacco with dust from this material.

Avoid breathing dust.

Handling (Physical aspects)

Avoid dust generation.

Exposure controls/Personal protection

Engineering controls

Use local ventilation to control dusts from cutting, sanding.

Personal protective equipment

Eye/Face protection

For machining operations wear appropriate protective equipment such as goggles or safety glasses with side shields.

Respirators

During grinding, sanding, or sawing operations use a NIOSH/MSHA approved air purifying respirator with dust/mist cartridge or canister if airborne particulate concentrations are expected to exceed permissible exposure levels.

Exposure guidelines

Exposure limits

VESPEL® polyimide parts and shapes all in synonym list VSP001

PEL (OSHA)   Particulates (not otherwise classified)
             15 mg/m³, 8 hours TWA, total dust
             5 mg/m³, 8 hours TWA, respirable dust

Other applicable exposure limits

Poly-N,N'-(p,p'-oxydiphenylene) pyromellitimide
PEL (OSHA)   None established
TLV (ACGIH)   None established
AEL* (DuPont) 10 mg/m³, 8 hours TWA, total dust
              5 mg/m³, 8 hours TWA, respirable dust

Graphite (None in ST-2000)

PEL (OSHA)   5 mg/m³, respirable dust, 8 hours TWA
TLV (ACGIH)   2 mg/m³, respirable dust, 8 hours TWA
AEL* (DuPont) None established

Molybdenum disulfide

PEL (OSHA)   5 mg/m³, and soluble compounds,
              as Mo
              Insoluble compounds: 10 mg/m³, total
              dust as 8 hours TWAs

TVL (ACGIH)   10 mg/m³, insoluble compounds,
              as Mo
              5 mg/m³, soluble compounds as Mo
              as 8 hours TWAs
AEL* (DuPont) None established

Polytetrafluoroethylene (PTFE)

PEL (OSHA)   None established
TLV (ACGIH)   None established
AEL* (DuPont) 10 mg/m³, 8 hours TWA, total dust
              5 mg/m³, 8 hours TWA, respirable dust

Physical and chemical properties

Physical data

Melting point	None
% volatiles	NA
Solubility in water	Insoluble
Odour	None
Form	Solid parts and shapes
Specific gravity	1,33 to 1,67

Stability and reactivity

Chemical stability

Stable at normal temperatures and storage conditions.

Decomposition

Decomposes with heat.
Decomposition temperature: Product performs without significant decomposition up to 288°C. Product will withstand short term excursions up to 482°C without significant decomposition.

Heating to temperature <288°C may cause evolution of particulate matter, which can cause polymer fume fever. Trace amounts of hydrogen fluoride and carbonyl fluoride may be evolved at 400°C from SP211, SP221 and D-resin types with larger amounts at higher temperatures.

Hazardous gases/vapors produced are carbon monoxide at temperatures over 300°C; small amounts of hydrogen fluoride from SP211, 221 and D-types.

Polymerisation

Polymerisation will not occur.

* AEL is DuPont's Acceptable Exposure Limit. Where governmentally imposed occupational exposure limits which are lower than AEL are in effect, such limits shall take precedence.

Toxicological information

Animal data

Polytetrafluoroethylene (PTFE)

The compound is not a skin irritant. Effects in animals from single exposure by inhalation to high concentrations of the dust include irritation of the lungs. Repeated oral doses resulted in no observable toxic effects except for alteration in the number of circulating white blood cells after long-term dosing (25% of diet for 90 days). Tests demonstrate no developmental toxicity in animals, and no genetic damage in animals or in bacterial cell cultures.

Molybdenum disulfide

Skin absorption LD50 >16 000 mg/kg in rabbits Oral LD50 >16 000 mg/kg in rats.

Repeated inhalation exposures of animals produced only an increase in respiration rate. A single ingestion exposure produced only marked diarrhea in animals. Repeated exposures produced no signs of toxicity.

Ecological information

Ecotoxicological information

Aquatic toxicity.
Toxicity is expected to be low based on the insolubility in water.

Disposal considerations

Waste disposal

Preferred options for disposal are (1) recycling, (2) incineration with energy recovery, and (3) landfill. The high fuel value of this product makes option 2 very desirable for material that cannot be recycled, but incinerator must be capable of scrubbing out acidic combustion products. Treatment, storage, transportation, and disposal must be in accordance with applicable federal, state/provincial, and local regulation.

Transportation information

Shipping information
DOT
Proper shipping name   Not regulated.

Regulatory information

U.S. federal regulations
TSCA inventory status   In compliance with TSCA inventory requirements for commercial purposes.

State regulations (U.S)
No substances on the state hazardous substances list, for the states indicated below, are used in the manufacture of products on this Material Safety Data Sheet, with the exceptions indicated.

Substances on the Pennsylvania Hazardous List present at a concentration of 1% or more (0,01% for special hazardous substances) – Graphite in types SP21, 22, 211, 221 and ST-types. Polytetrafluoroethylene in SP211 and 221. Polytetrafluoroethylene is listed, but we believe it was listed in error, and have petiotioned to have it delisted.

Warning – *Substances known to the State of California to cause cancer, birth defects or other reproductive harm* – None known.

Substances on the New Jersey Workplace Hazardous Substance List present at a concentration of 1% or more (0,1% for substances identified as carcinogens, mutagens or teratogens) – Molybdenum sulphide.

Other information

NFPA, NPCA-HMIS
NFPA Rating
Health: 2
Flammability: 1
Reactivity: 0

Additional information
MEDICAL USE – CAUTION: Do not use in medical applications involving permanent implantation in the human body. For other medical applications see DuPont CAUTION Bulletin No. H-50102.

The data in this Materials Safety Data Sheet relates only to the specific material designated herein and does not relate to use in combination with any other material or in any process.

Responsibility
for MSDS: J.P. Bollmeier

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              Chestnut Run Plaza 713
              Wilmington, DE 19880-0713

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