VESPEL®

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LINE

TYPICAL PROPERTIES OF VESPEL® PARTS & SHAPES

DuPont™ Vespel®
forward engineering

DUPONT®

The miracles of science™

Contents

Introduction

Thank you for your interest in DuPont's VESPEL® polyimide parts. As part of the VESPEL® product team, we look forward to this opportunity to present our product and services to you.

DuPont's VESPEL® team has evolved to uniquely meet the changing needs of the world-wide marketplace. We offer you advanced materials and dedicated professionals: design engineers, production engineers well versed in state-of-the-art manufacturing techniques for both resin and parts, and others dedicated to ensuring that your consistently high quality VESPEL® parts and shapes get to you on a timely basis.

We work to make your product a success – from concept to design, component analysis, composition selection, prototyping, testing, quality control and on through production of commercial parts.

This VESPEL® brochure is a collection of articles relating to the use of VESPEL® polyimide – some background on its development, its applications, demonstrations of its cost effectiveness, and details on some of its technical properties.

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 us at one of the offices listed on the back cover.

All VESPEL® parts are ISO 9001 and QS 9000 certified.

VESPEL® parts deliver an outstanding combination of properties

VESPEL® parts are custom-made by DuPont from SP polyimide resins to combine the best characteristics of plastics, metals and ceramics. They resist wear, fight creep, and they practically never melt – properties that allow them to survive a broad range of conditions.

For example, VESPEL® parts

- provide *outstanding wear resistance* in lubricated or unlubricated environments (dry pressure velocity limits to 12 MPa · m/s, and even higher with lubrication),
- can *operate continuously* from cryogenic temperatures to 288° C, with short-term use to 482° C and above,
- can *withstand loads* at temperatures beyond the reach of most other plastics,
- have low thermal and electrical conductivity,
- offer *sealing compliance* but resist permanent deformation. They provide a more reliable seal than many metal-to-metal seals machined to much tighter tolerances,
- are *easily machined* without special equipment or procedures.

VESPEL® can be machined as easily as brass

While DuPont can supply finished machined parts, you can easily do your own machining using VESPEL® shapes.

With standard metal-working equipment, you can machine VESPEL® shapes to tolerances once considered too close for plastic materials. In most cases, the techniques used for machining metals such as brass are directly applicable. VESPEL® shapes are relatively easy to machine because of their high mechanical strength, stiffness and dimensional stability at machining temperatures.

For a complete guide to machining parts from VESPEL® shapes, ask for a copy of the Design Handbook.

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.

Direct-formed parts for cost savings on larger quantities

Machining parts from VESPEL® shapes is usually the most practical route to producing small quantities, prototypes, or parts with highly complex geometry.

For production quantities of 500 or more, VESPEL® parts can often be most economically fabricated by the DuPont direct-forming process.* Direct forming uses powder metallurgy techniques to produce finishe or semifinished parts, and minimises material wastes.

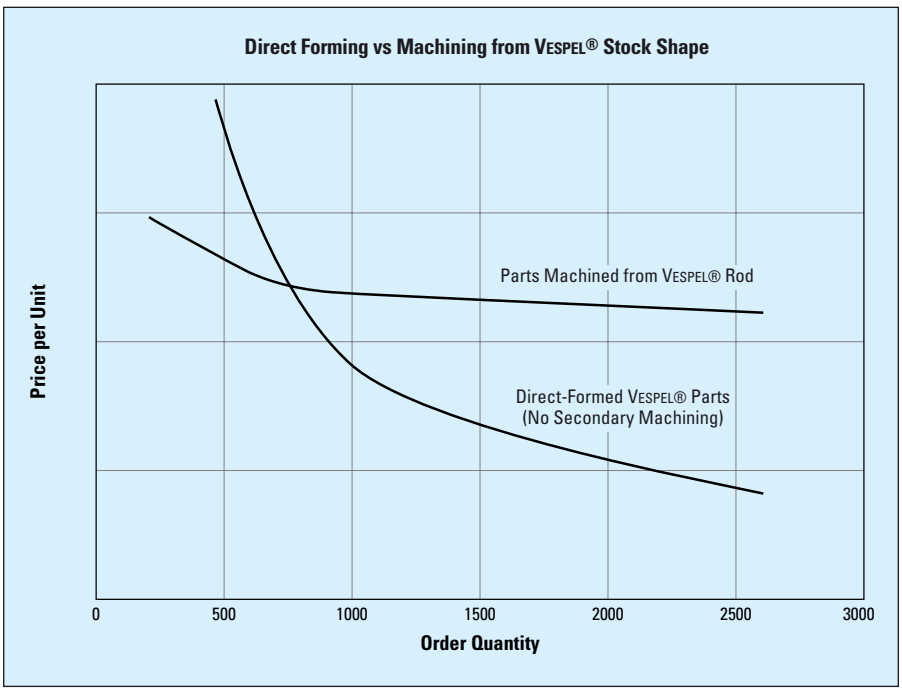
Machining can often be eliminated. Long production runs also produce labour savings which can be passed along as lower part prices.

The chart below gives an example of how part cost varies with quantity for an uncomplicated polyimide ring.

Due to the variety of factors that arise in determining the most economical fabrication process for an individual part, you should consult with a VESPEL® sales engineer at the earliest stage of part design.

* In some cases, depending on part size or complexity, direct-forming may be economical at even lower quantities.

Typical VESPEL® Part Fabrication Economics



VESPEL® – the material for the new age

Today's sophisticated engineering requires parts that are smaller, lighter and capable of performing over a wider temperature range than ever before. As designs become more sophisticated, and product warranties longer DuPont's VESPEL® parts are being specified more and more often. The reason is simple. VESPEL® parts exhibit a superior combination of properties in a variety of applications requiring low wear and long life in severe environments.

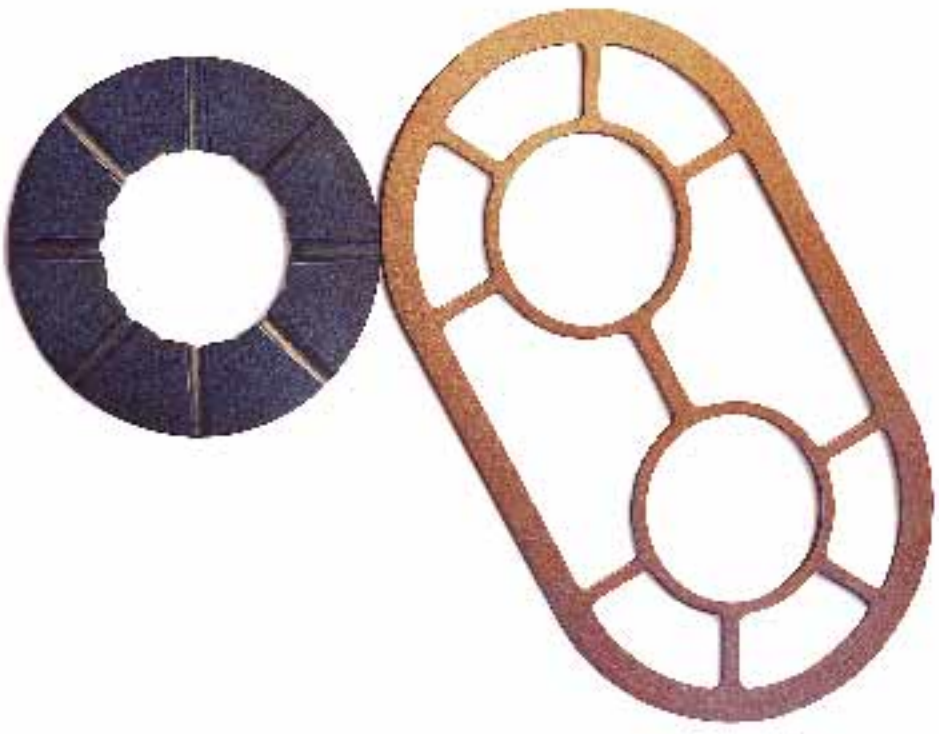
Since 1963, high-strength, lightweight VESPEL® parts have helped foster the revolution in aircraft engine design and performance. Today, many dependable VESPEL® parts are performing in almost every let engine made in the Western world. Millions more are operating successfully in automobiles, large on- and off-road vehicles, farm equipment, business machines, electronic equipment – and wherever else trouble-free performance is vital to success.

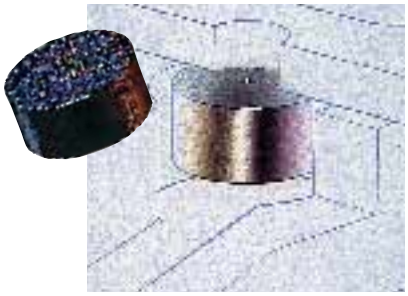
Although they originally adopted VESPEL® as a "problem solver," engineers in a variety of fields now "think VESPEL®" first – to replace metal, plastic and ceramic parts. High-performance VESPEL® polyimide parts include: rotary seal rings, thrust washers and thrust discs, bushings, flanged bearings, printer platen bars, plungers, printer wire guides, stripper fingers, spline couplings, wear strips, locknut inserts, valve seats, check valve balls, thermal and electrical insulators.

With plants in the United States, Belgium and Japan, DuPont manufactures both SP resin and VESPEL® parts within a fully integrated global manufacturing system.

VESPEL® parts made from DuPont SP polyimide resin are virtually in a class by themselves. Available in five compositions (see Technical Data, pages 10–13), VESPEL® parts offer an outstanding combination of properties: excellent resistance to extreme heat, good mechanical strength, good solvent resistance, low coefficient of friction, high dielectric strength, excellent dimensional stability, outstanding wear resistance, sealing compliance, high compressive strength, outstanding radiation resistance, low outgassing for vacuum applications and toughness.

VESPEL® quality is worth the investment – providing savings through simplified assembly operations, increased reliability, extended component life and reduced wear on mating components. Global manufacturing companies depend on DuPont and VESPEL® to deliver. These include Bosch, Caterpillar Chrysler, Ford, General Electric, General Dynamics, General Motors, Hitachi, Kodak, Rockwell International, Toyota and United Technologies.





VESPEL® valve disc reduces wear and withstands impact

A precision 0,38 mm diameter hole in the VESPEL® disc of a transmission check valve was required to accurately control the bleedback of automatic transmission fluid. Metal could not be economically drilled at the required hole diameter.

The VESPEL® parts are custom made with tiny, debris-free, direct formed holes as specified. They reduce wear against the aluminium valve body and withstand repeated impact without permanent deformation.

Customer complaints decline with VESPEL® seats

In hydraulic pressure relief valves on farm tractors, VESPEL® seats provide a no-leak seal in 135° C hydraulic oil while resisting 25,8 MPa without creep. The VESPEL® seats conform to the balls' shape and reseal even in the presence of particulate contaminants. The VESPEL® seats increase system reliability and reduce customer complaints.

Self-lubricating VESPEL® stemguide extends life of pneumatic controls

A VESPEL® stem-guide allows a maker of pneumatic controls to increase the upper service temperature and extend the reliability of its top-of-the-line valve. The VESPEL® part performs reliably at 260° C. It remains self-lubricating, exhibits a low coefficient of friction even at the high service temperatures of the valve, and withstands repeated impact without deformation.

An outstanding performer

VESPEL® SP polyimide parts offer an outstanding mix of the physical characteristics of metals, ceramics and plastics, combined with their own outstanding properties. VESPEL® parts resist wear, fight creep, and practically never melt, allowing them to operate in the demanding environments of engines, transmissions and high-speed printers. VESPEL® parts perform reliably under a broad range of conditions, such as:

- lubricated or unlubricated environments, at high pressure and/or velocity, with outstanding wear resistance. VESPEL® parts perform at pressure velocities (PVs) of up to 40 MPa · m/s with lubrication and 12 MPa · m/s without lubrication;
- temperatures from cryogenic up to 288°C continuously, with short-term use to 482°C;
- hydraulic, automotive and many industrial fluids and solvents.

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.

VESPEL® can be superior to metals in many ways

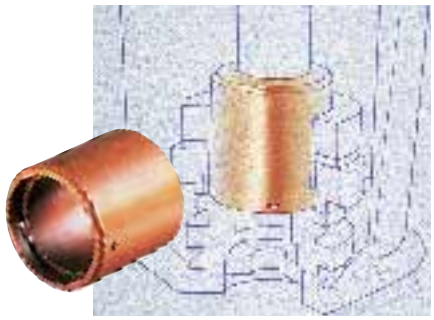
VESPEL® parts provide reliable sealing, even in contaminated fluids. Because of their compliance, they can provide a more reliable seal than many other sealing systems machined to much tighter tolerances. VESPEL® parts can also reduce manufacturing costs, such as expensive hand lapping or secondary grinding. Further, VESPEL® parts weigh less than metal parts, which can reduce inertia, allowing for faster movement and change of direction while minimising damage to mating surfaces and providing quieter operation. VESPEL® parts have a low coefficient of friction and resist corrosion. They have outstanding resistance to fatigue and peening or repetitive impact deformation.

VESPEL® parts can be superior to other plastics in many ways

VESPEL® parts have an outstanding continuous-use temperature range, excellent dimensional stability and, unlike most plastics, are non-flammable. VESPEL® parts perform without melting or softening and have high resistance to creep. VESPEL® parts resist radiation more effectively than most other plastics and possess outstanding compressive strength. VESPEL® parts provide an effective seal against thin gases and are also compatible with oxygen. VESPEL® parts exhibit ultra-low outgassing even in high vacuums. VESPEL® parts do not soften, and almost never melt. They are chemically compatible with most fuels, soIvents, lubricants, and hydraulic fluids. Finally, VESPEL® parts exhibit superior wear resistance compared to most plastics.

VESPEL® parts have three important advantages compared to ceramics

VESPEL® parts are more compliant than ceramics. VESPEL® parts seal better at a lower pressure and are less brittle while exhibiting excellent dimensional and thermal stability.



VESPEL® baffle increases torch life

L-Tech was dissatisfied with the performance of the ceramic baffle in the plasma cutting torches it manufactures. The electrodes had to be replaced every eight to ten hours and, each time, the baffles were also removed and reinserted. Many of the ceramic baffles were damaged or broken in the process.

In their search for a more durable baffle, engineers tested a variety of plastics. Only VESPEL® SP polyimide parts provided the heat resistance, creep resistance and flexibility necessary for improved torch operation. The new VESPEL® gas-swirl baffles lasted more than six times longer than their predecessors. They could be handled numerous times without damage. And the more compliant VESPEL® polyimide parts can be made with a tighter clearance than the ceramic parts, thus providing a tighter seal against the cutting torch's copper nozzle. By switching to VESPEL® baffles, L-Tech was able to increase life of the baffle from approximately 15 to 100 hours.

The partner ship you can count on

To ensure your success, DuPont and VESPEL® give you something that you simply don't get from most other matenals suppliers custom-made quality parts combined with professional assistance and single-source accountability from resin development to part concept and design to finished parts.

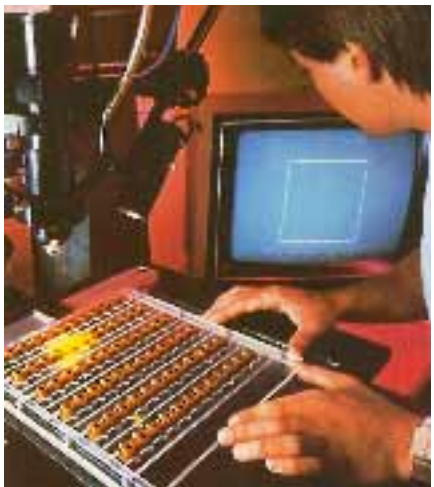
The process begins with DuPont technical consultants. Years of practical experience allow our sales engineers to recommend ultra high-performance VESPEL® parts that not only fulfill a particular function, but which can also simplify your entire assembly. They can help you make a higher quality, lower cost product a reality – from designing new components to troubleshooting existing ones, and from simplifying part design to helping select the right resin composition.

The partnership continues with DuPont design and manufacturing professionals and tooling experts. Our production facilities in the United States, Europe and Japan have produced hundreds of millions of custom VESPEL® parts – tiny to large, simple to complex, direct-formed, secondary-machined, or machined entirely from standard shapes.

We also offer a complete line of standard shapes for machining your own prototype, as well as low-volume or complex commercial parts.

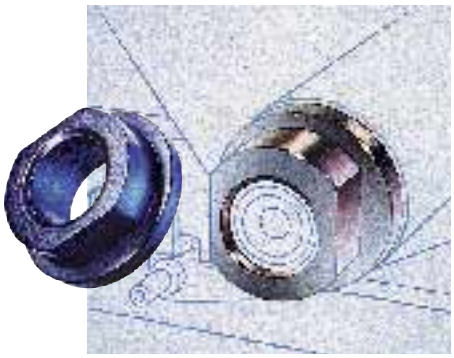
DuPont's high quality manufacture of SP po yimide resin and VESPEL® parts includes checkpoints at every step of the production process to assure consistency. State-of-the-art Statistical Process Control (SPC) is employed to meet our consistently high quality standards and the requirements of the world's most demanding original equipment manufacturers.

For more than 20 years, DuPont's VESPEL® Parts Team has been responding to the needs of design and materials engineers. Come to DuPont for the quality materials, parts and the "partnership advantage" in designing, prototyping, manufacturing and testing which will help you meet your toughest performance challenges.



The inherent lubricity of VESPEL® parts simplified an entire assembly

This one-piece VESPEL® film guide replaces a complex machined aluminium roller with press-fit ball bearings. The VESPEL® part reduces machining assembly time, and acts as its own self-aligning and self-lubricating bearing.



VESPEL® bearings reduce service calls and improve product performance

The toner liquid used in a desktop copier was leaching the oil from porous bronze bushings, causing increased wear in the bearing. The oil was contaminating the toner and ruining the quality of the copies. VESPEL® bearings eliminate the need for lubrication and provide excellent wear characteristics.

VESPEL® parts can help improve your profitability

For years, designers have turned to DuPont for VESPEL® parts when other materials have failed. Today, they're turning to VESPEL® parts for another critical reason – to cut overall costs from the start.

In nearly everx case, VESPEL® parts pay for themselves many times over by keeping reliability high – and manufacturing costs, maintenance costs and warranty claims low. VESPEL® parts can make possible the following:

Parts consolidation. Often, the function of two or more existing parts can be combined in a single VESPEL® piece, as with flanged bushings.

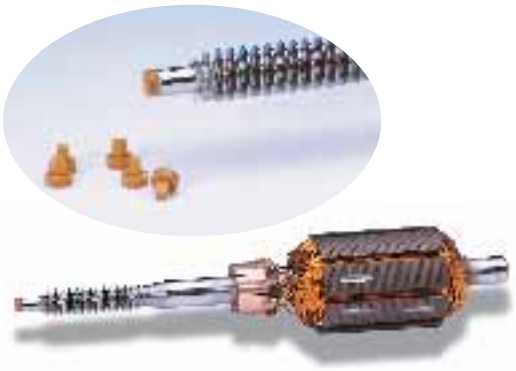
Machining costs elimination. VESPEL® parts can often be direct-formed to fit a specific application, eliminating the need for costly machining.

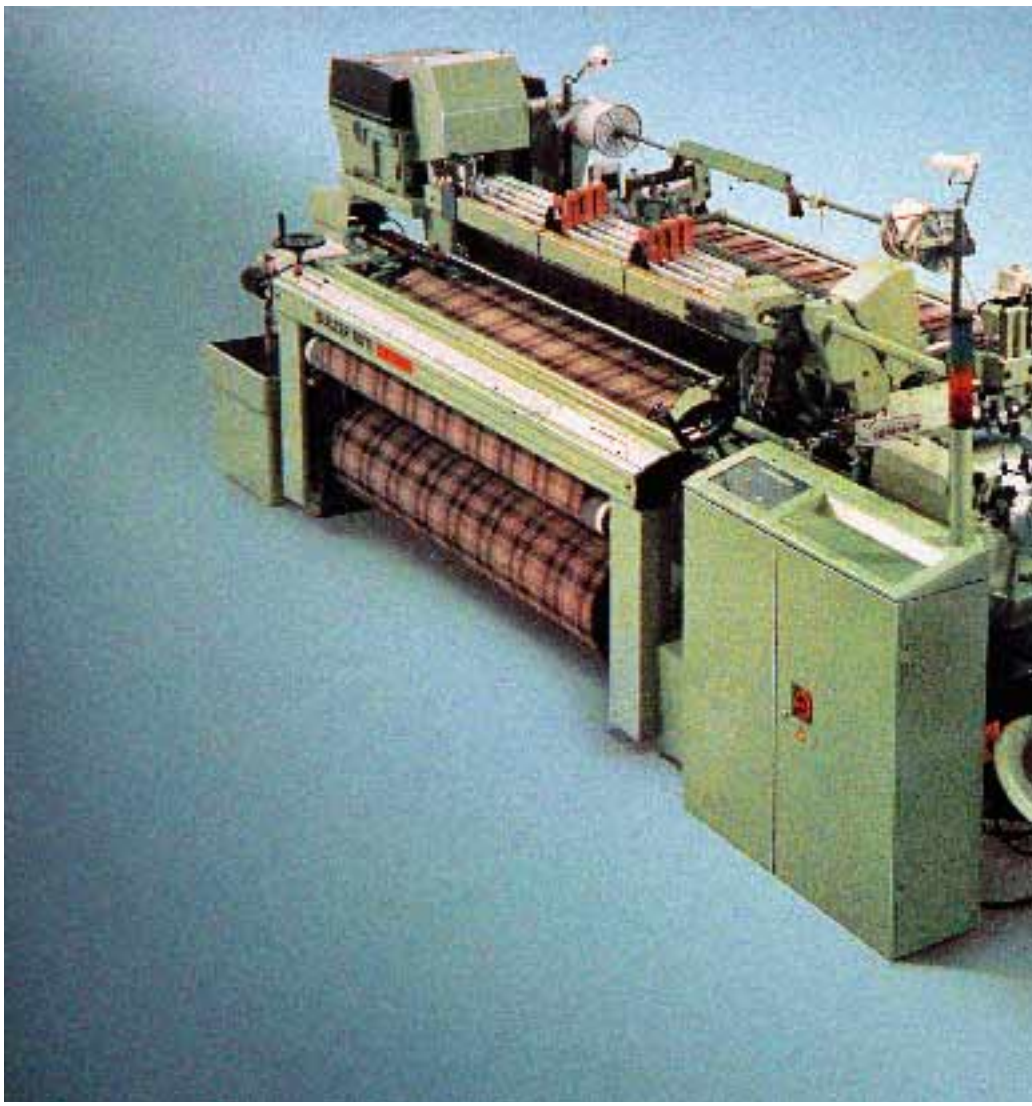
Capital equipment life extension. With their unique combination of properties, VESPEL® parts help preserve the life of critical capital equipment, such as sophisticated office machines or heavy machinery. In fact VESPEL® parts provide increased service life and reliability in the transmissions of rigorously operated vehicles such as heavy trucks and buses, as well as in automobiles.

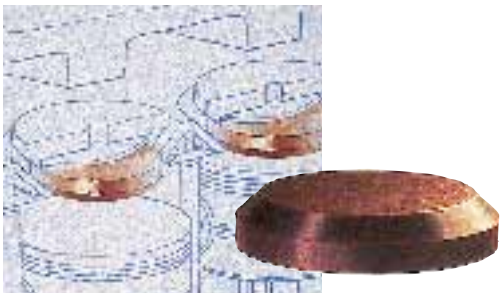
Maintenance and warranty claims minimisation. The ability of VESPEL® parts to work in critical environments without or with only marginal lubrication can reduce mamtenance and increase reliability.

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 Statistical 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 a substantial cost savings.

Although VESPEL® parts may have higher initial costs than some other materials, they can save money over time. Consistent quality, dependable performance, longer life and reduced warranty and maintenance costs have proven that VESPEL® parts are the most effective solution for many manufacturers and end users.

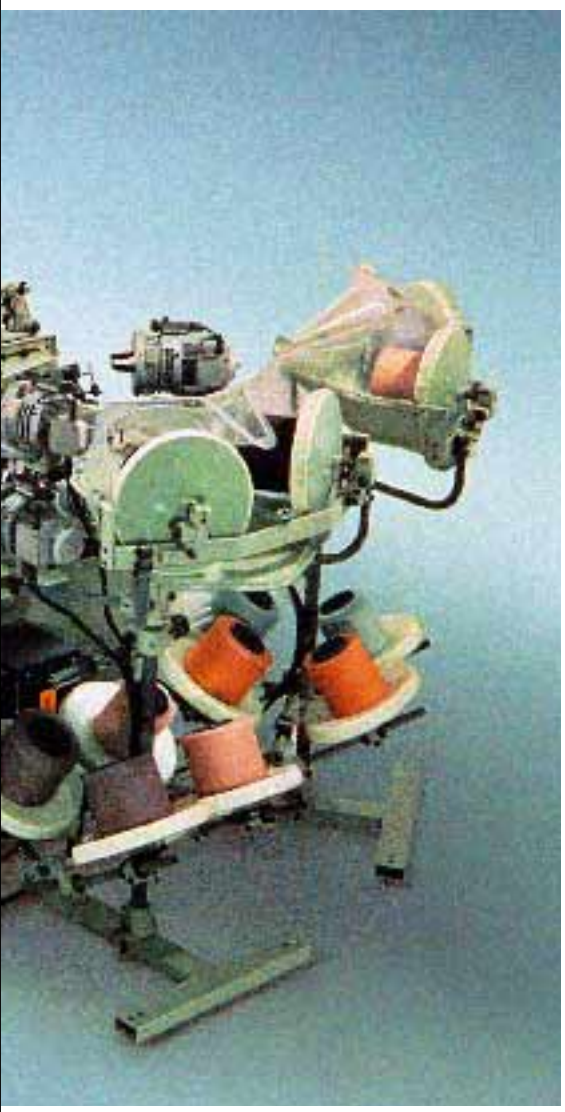






VESPEL® disc helps save supermarkets money with improved refrigeration efficiency

Copeland Corporation spent several years looking for a material to meet the requirements of a new refrigeration compressor valve system. Many metals and plastics were tested – none of them had the combination of creep, fatigue and wear resistance at high cylinder temperatures which VESPEL® provided. Even after extended service, the VESPEL® disc showed only the slightest wear, fatigue and creep and the disc surface was not abraded by metal or dirt particles. Each VESPEL® disc is expected to last for 15 years. The VESPEL® parts allowed Copeland to design a compressor which will cut a food store's electrical costs for refrigeration by 10 to 20 per cent.



VESPEL® seal rings help reduce manufacturing costs in many ways

Toughness and flexibility make them easier to assemble than cast iron, eliminating the need for special assembly fixtures. And there is less breakage, especially with smaller diameter seal rings. In addition, sufficient stiffness helps keep VESPEL® seal rings from bending out of shape and being cut during assembly often a problem with rings of PTFE. VESPEL® parts are compliant, so mating parts can have wider tolerances and rougher surfaces, thereby reducing machining costs. Finally, VESPEL® can function as a bearing surface as well as a seal… providing the possibility of added design economies.

VESPEL® rings save millions – by stopping chrome-on-chrome wear

Compressor bleed-valve life was increased by 50% in a U.S. Air Force programme to replace chrome-plated steel piston rings with VESPEL® SP rings. Friction between the metal rings and chrome-plated cylinders was causing premature failure on J-57 and TF-33 jet engines. Engineers selected VESPEL® rings to replace the chrome piston rings after tests showed that they could withstand up to 205 000 cycles at temperatures above 315° C without failing. The VESPEL® rings cost far less than traditional carbon piston rings. An estimated $ 2.7 million reduction in maintenance costs is anticipated.

VESPEL® seal rings help reduce warranty costs by extending service life of equipment

VESPEL® parts can help machinery last longer in two important ways: by reducing wear and by withstanding the extreme temperatures created by the high pressure/velocities (PVs) of severe operating conditions or marginal lubrication. They outperform many other materials in dusty or contaminated environments, and work well in transmission and hydraulic fluids.

VESPEL® SP polyimide technical data

SP polyimide, developed by DuPont, has a unique combination of properties which makes it the ideal solution for a variety of applications.

Please note that all of the property data discussed in this brochure are based upon laboratory tests and/or performance of VESPEL® parts in specific applications. The maximum use temperature, PV limit and other performance parameters of virtually all engineering materials will vary somewhat from application to application and between laboratory data and actual applications, depending upon a number of factors intrinsic to each application. Therefore the only way to determine how VESPEL® parts will perform in your application is to test them – in your application.

Technical discussion of the properties of VESPEL®

Dimensional stability

VESPEL® parts made from DuPont SP polyimide resin exhibit excellent overall dimensional stability compared to other plastics due to a combination of outstanding key properties. Most important is the fact that VESPEL® parts have no observable softening or melting point. Other contributors to VESPEL®'s excellent dimensional stability include low coefficient of thermal expansion (some grades are comparable to aluminium), and excellent resistance to creep and repetitive impact deformation.

This stability allows VESPEL® parts to be machined to tolerances once thought to be too tight for plastics and even allows VESPEL® to be used as moulded-in inserts in injection mouldable thermoplastic parts. This stability also means that your VESPEL® parts will maintain their dimensions and functionality under some of the harshest operating conditions.

VESPEL® combines this excellent dimensional stability with a high degree of toughness not found in some of the more traditional "dimensionally stable" polymers.

Temperature resistance

VESPEL® parts almost never melt, and can operate continuously from cryogenic temperatures to 288° C with excursions to 482° C. Owing to superior thermal stability, VESPEL® parts maintain consistently high performance, even when subjected to high temperatures for extended periods.

Many physical properties of VESPEL®, such as tensile strength, elongation, flexural modulus and compressive strength, may be comparable to those of some high-performance polymers at room temperature. But VESPEL®'s excellent retention of these properties at both very high and very low temperatures, even after extended service at extreme temperatures, makes VESPEL® the high-performance choice for applications involving operation at other than room temperature.

Wear resistance

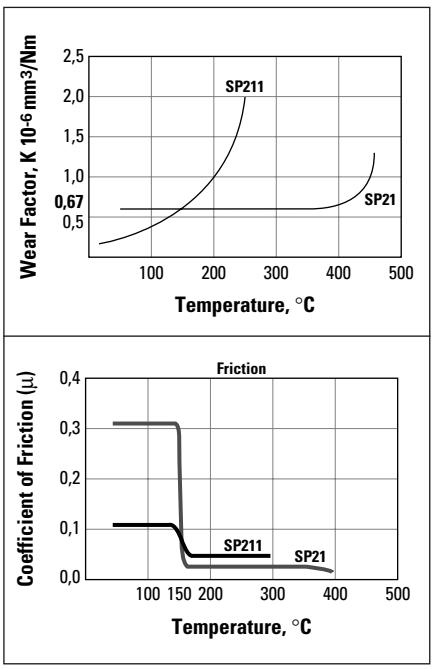
Like many other plastics, VESPEL® parts provide corrosion-resistant, gall-resistant, low-wear and low-friction surfaces – even in non-lubricated environments. But that is where the similarities end.

VESPEL® parts won't melt or soften – even at 482° C. They have excellent oxidative stability and creep resistance. This helps VESPEL® parts deliver consistently superior wear performance over a broad temperature range even when the temperature at the bearing interface is substantially higher than ambient, due to the frictional heat generated by operating at high pressures and/or velocities.

VESPEL® bearings have performed at up to 12 MPa · m/s, unlubricated, and up to 40 MPa · m/s, lubricated.

VESPEL® parts are naturally tough and don't require the addition of abrasive fillers or fibres to enhance part performance. This reduces wear of the mating surface. The superior oxidative ability of VESPEL® is also an advantage when compared with thermosets.

Wear factor and friction coefficient for unlubricated operation against mild carbon steel



Sealing compliance

VESPEL® valve seats, poppets and balls provide sealing compliance while resisting permanent deformation. This means that VESPEL® parts can provide positive seals even in fluids containing particulate contaminants. And they can provide more reliable seals than metal-to-metal seals machined to much tighter tolerances – a feature which can reduce manufacturing costs by eliminating the need for expensive hand-lapping of the mating surface.

VESPEL® parts are tough. During an application test of valve seats designed to test the failure limit of valve components, the pressure on a carbide ball in a VESPEL® seat was increased to levels far beyond normal operating conditions, until the ball was finally forced through the VESPEL® seat. However, in subsequent testing on that same VESPEL® valve seat, the seat had recovered sufficiently to still provide a positive seal at normal operating pressures for that system.

Radiation resistance

VESPEL® parts perform well in radioactive environments, even at relatively high dosage rates. At exposure levels up to and including 1×10^8 rads of gamma radiation, VESPEL® bars displayed less than 1,0% 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*.

Low outgassing

Weight loss in vacuum at high temperatures is low for VESPEL® parts. In tests run by NASA in high vacuum, VESPEL® samples, which were first dried at 93° C to remove water, had a weight loss rate of less than 10^{-10} grammes / cm^2 / s at temperatures below 260° C.

Fabricating VESPEL®

Machining

VESPEL® shapes are relatively easy to machine because of their inherent mecanical 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 brass are directly applicable.

Direct-formed VESPEL® parts

While VESPEL® shapes are easy to machine, direct forming is often the most economical process by which to produce parts, especially if you require more than 500 to 1000 VESPEL® parts per year.

* This represents the mean of a group of treated samples compared to bars receiving no radiation exposure.

Summary of typical properties SP polyimide resins (SI units)

	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	23	D-1708	MPa	86,2	72,4	65,5	62,0	51,7	48,3	44,8	51,7	58,5
		260	or E8†		41,4	36,5	37,9	30,3	23,4	26,2	24,1	24,1	
	Strain at break	23	D-1708	%	7,5	7,5	4,5	5,5	3,0	2,5	3,5	5,5	4,0
		260	or E8†		6,0	7,0	3,0	5,2	2,0	2,0	3,0	5,3	
	Flexural strength	23	D-790	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	D-790	MPa	3102	2482	3792	3171	4826	4826	3102	2758	3275
		260			1724	1448	2551	1792	2758	2758	1379	1379	1862
	Compressive stress	23	D-695	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 % strain				51,0	33,1*	45,5	33,8*	41,4	25,5*	37,2	27,6*	
	Compressive modulus	23	D-695	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	D-732	MPa	89,6		77,2						
	Izod notched impact strength	23	D-256	J/m	42,7		42,7						21,3
	Izo, unnotched impact strength	23	D-256	J/m	747		320						112
	Poisson's ratio	23			0,41		0,41						
WEAR AND FRICTION	Wear rate††			m/s × 10^{-10}	17–85	17–85	6,30	6,30	4,20	4,20	4,90	4,90	17–23
	Friction coefficient**												
	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 expansion	23 to 260	D-696	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	D-621	%	0,14	0,20	0,10	0,17	0,08	0,14	0,13	0,29	0,12
	Deflection temperature at 2 MPa		D-648	°C	~360		~360						

	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	Ω·m	10^{14}-10^{15}		10^{12}-10^{13}						
	Surface resistivity	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.

Remark:

M: Parts machined out of shapes material.

DF: Parts obtained by «Direct Forming» process.

Preliminary properties of new SP polyimide resins

	Property	Temp. °C	ASTM Method	Units	SP221 DF	SP262 DF
MECHANICAL	Tensile strength	23	D638	MPa	38,6	37,9
		260	or E8			19,3
	Strain at break	23	D638	%	3,5	1
		260	or E8			0,7
	Flexural strength	23	D790	MPa	55,1	
		260			31	
	Flexural modulus	23	D790	MPa	3445	
		260			2205	
	Tensile modulus	23	D638	MPa		8410
		260	or E8			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				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		0,44
	PV = 3,5 MPa · m/s			$\times 10^{-6}$		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 lineal 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

Note: SP221 and SP262 Stock Shapes are not yet available.

Typical properties of Direct-Formed VESPEL® ST parts

	Property	Temp. °C	ASTM Method	Units	ST2010 DF	ST2030 DF
MECHANICAL	Tensile strength	23	D638	MPa	68	57
		150			49	
		260			32	
		300			26	
	Strain at break	23	D638	%	10,0	4,9
		150			10,0	
		260			9,8	
		300			9,7	
	Tensile modulus	23	D638	MPa	2758	3930
	Izod notched impact strength	23	D256	J/m	53	
	Compressive strength		D695	MPa		
	1 % strain	23			15	
	10 % strain				82	
	ultimate				269	155
	Compressive modulus	23	D695	MPa	1827	1207
ELECTRICAL	Dielectric strength	23	D149	kV/mm	10,4	
	Dielectric constant	23	D150			
	100 Hz				4,80	300
	10 kHz				4,78	110
	1 MHz				4,70	40,6
	Dissipation factor	23	D150			
	100 Hz				0,0014	6,90
	10 kHz				0,0023	0,65
	1 MHz				0,0075	0,30
	Volume resistivity	23	D257	ohm·cm	$3{,}2\times10^{16}$	$4{,}8\times10^{7}$
	Surface resistivity	23	D257	ohm	$2{,}0\times10^{16}$	$2{,}6\times10^{6}$
MISCELLANEOUS	Thermal conductivity			$[W\cdot cm/cm^2\cdot °C]$		
		23	F433	$\times10^{-3}$	5,0	9,7
	Coefficient of linear thermal expansion	23–260	D696	µ/m/°C	48	32
	Water absorption % change (weight),					
	24 h	23	D570		1,3	0,5
	48 h				3,1	1,3
	Deformation under 14 MPa load	23	D621	%	0,18	
		50			0,38	
	Specific gravity	23	D272		1,38	1,44

Note: ST Stock Shapes are not yet available.

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