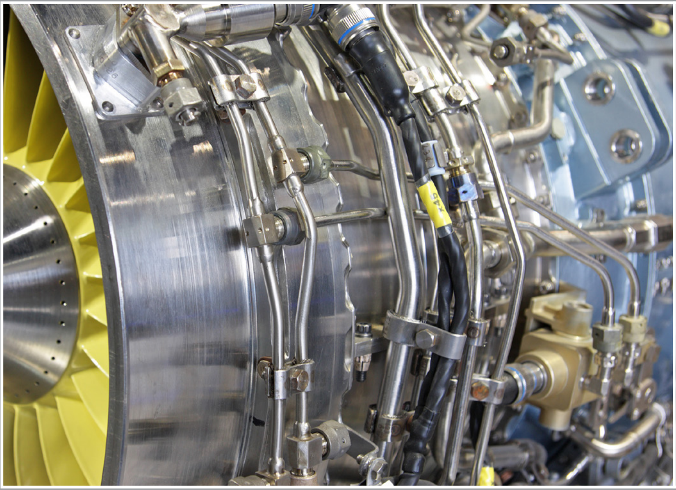
DUPONT™ VESPEL® POLYIMIDES – HIGH PERFORMANCE POLYMERS FOR AEROSPACE VALVE SEATS AND SEALS



Curbell Plastics, Inc.
Ryan Nelson & Keith Hechtel – Authors

Table of Contents

DuPont™ Vespel® polyimide materials have unique properties that allow them to perform over a broad range of temperature, pressure, and vacuum conditions.

DuPont™ Vespel® seats and seals have been widely used to increase the operating temperature range, improve reliability, and extend the service life of aerospace valves. This paper describes the performance advantages of DuPont™ Vespel® parts & shapes and the benefits of specifying DuPont™ Vespel® parts & shapes for critical-service aerospace valve applications.

LIMITATIONS OF ALL-METAL SEALING SYSTEMS

Metals are relatively high modulus (stiff) materials, which can prevent metal valve seats and seals from conforming to small irregularities on mating metal surfaces. These irregularities can create leak paths. Because of this, metal to metal seals must be manufactured via costly machining and polishing processes in order to achieve the mirror-like surface finishes and tight dimensional tolerances required for sealing.

Metal on metal valve components that slide against one another during actuation may gall, especially in cases where liquid lubricants cannot be used. Debris from galling can create contamination, which has the potential to prevent fluid handling systems from operating properly. Excessive galling can also lead to a valve seizing and failing.

Metal components are relatively heavy and moving metal parts tend to be noisy. Both of these characteristics are undesirable in aerospace applications.

Light weight and the ability to operate at elevated temperatures are important characteristics for many aerospace seals.

Vespel® SP-21 ball valve seats are less abrasive on mating metal surfaces when compared with metal to metal contact.

ADVANTAGES AND LIMITATIONS OF SEALS MANUFACTURED FROM CONVENTIONAL THERMOPLASTICS

Many engineering thermoplastics offer the advantage of having moderate modulus at room temperature. This allows polymer sealing components to conform to minor irregularities on mating surfaces and achieve seals with relatively open dimensional tolerances and modest surface finishes. Engineering plastics also tend to have low friction when sliding against metal surfaces during valve actuation. This results in smooth operation and extended part life.

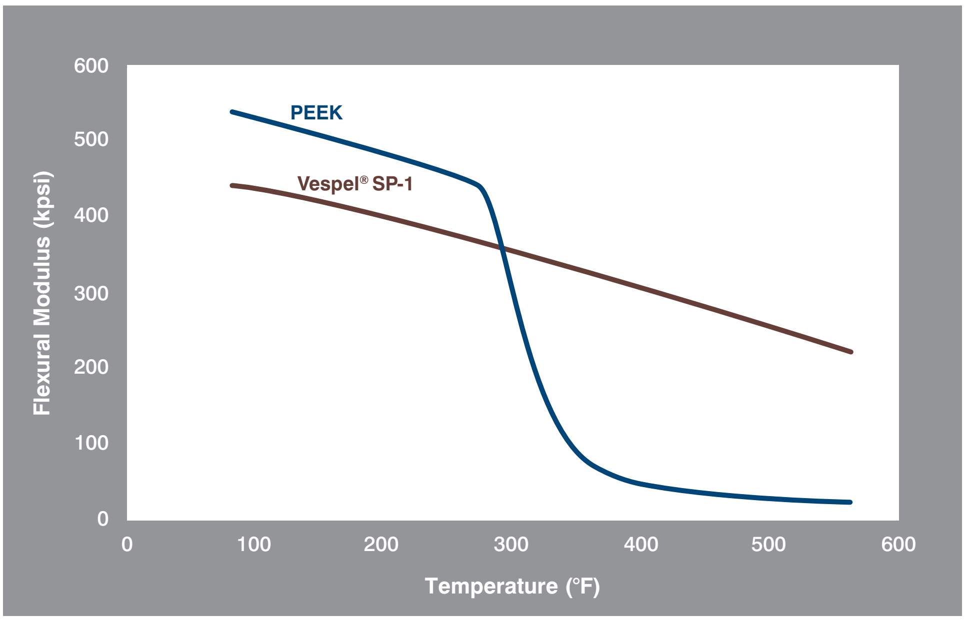
Many engineering plastics become soft and exhibit accelerated creep and stress relaxation at elevated temperatures. They may also degrade and become brittle if exposed to elevated temperatures over long periods of time. These characteristics make standard engineering plastics unsuitable for some high temperature sealing applications, especially for systems that involve high pressures where stress relaxation and/or brittle cracking can result in leak paths. Additionally, many engineering plastics have high rates of thermal expansion compared with metals, which makes it difficult to achieve a good fit with mating metal parts, especially for valves that have a wide operating temperature range. Finally, many engineering plastics become stiff and brittle at cold temperatures. This embrittlement can result in polymers becoming too stiff to achieve a seal against a mating metal surface. Plastic seals under high compressive loads at cold temperatures may even crack during use.

HIGH TEMPERATURE PERFORMANCE OF DUPONT™ VESPEL® PARTS & SHAPES

DuPont™ Vespel® "thermoset" polyimide materials have unique properties that allow them to perform over a broad range of temperature, pressure, and vacuum conditions.

Unlike standard engineering thermoplastics such as nylon, PCTFE, and PEEK, DuPont™ Vespel® parts & shapes can operate reliably in temperatures ranging from cryogenic to 500˚F, with excursions to 900˚F. Figure 1 shows the flexural modulus of Vespel® SP-1 and PEEK at various temperatures. PEEK (like most thermoplastics) quickly loses its mechanical properties above the onset of its glass transition temperature (289˚F for PEEK), while Vespel® maintains significant strength and stiffness at temperatures well above 500˚F. This allows DuPont™ Vespel® seals to function at elevated temperatures in certain valve applications even when high pressures are involved.

Figure 1. **Flexural Modulus of DuPont™ Vespel® SP-1 and Virgin PEEK at Various Temperatures**



Unlike traditional thermoplastics such as PEEK, DuPont™ Vespel® maintains significant modulus (stiffness) at elevated temperatures. This results in superior sealing performance for valves that must operate at high temperatures and presssures.

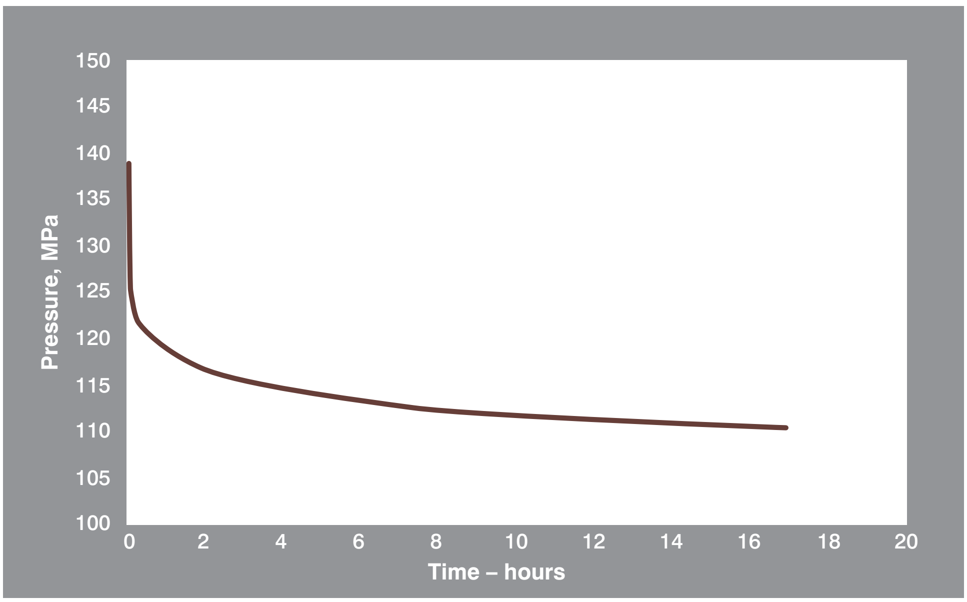
Source: McKeen (2008) and DuPont™ (1993)

LONG-TERM SEALING PERFORMANCE

Plastic seals must "press" against mating metal surfaces with sufficient force to prevent pressurized process fluids from leaking between the polymer and the metal. Because of this, high pressure sealing requires that a polymer seal maintain apparent compressive modulus (stiffness) when compressed between metal parts. Seals manufactured from conventional engineering thermoplastics have a tendency to stress-relax over time, which can create leak-paths in a valve. Polymers relax more quickly at elevated temperatures.

The inherent resistance of DuPont™ Vespel® to stress relaxation allows it to maintain much of its apparent modulus over extended periods of time, resulting in long-term sealing performance. Figure 2 and Figure 3 illustrate Vespel® SP-1's ability to maintain apparent modulus at room temperature and at elevated temperatures.

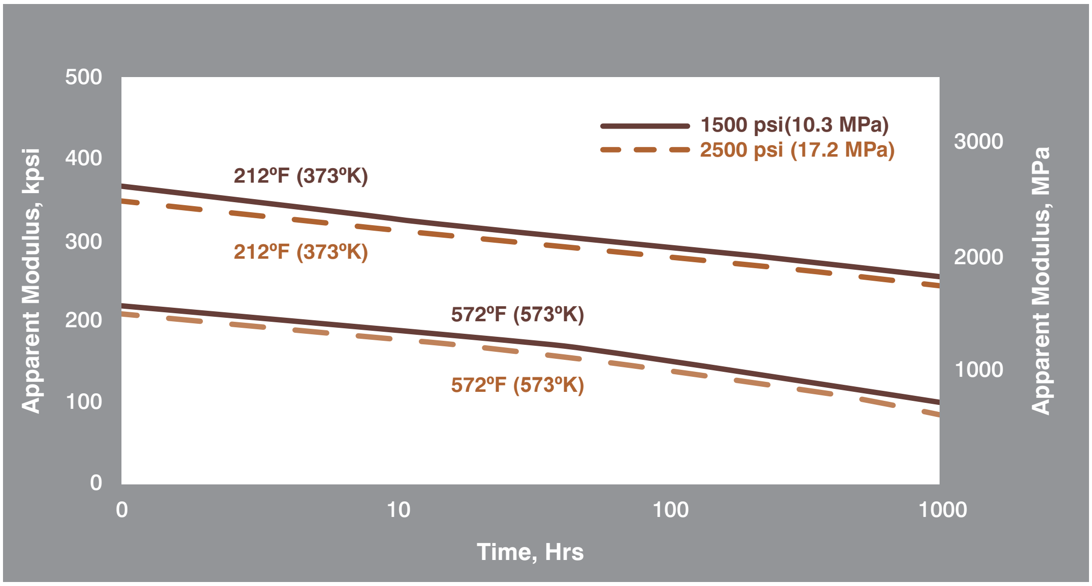
Figure 2. **Stress Relaxation of Vespel® SP-1 at 68°F. Pressure vs. Time at 15% Constant Compression**



Vespel® SP-1 maintains much of its apparent compressive modulus at constant 15% compression at room temperature.

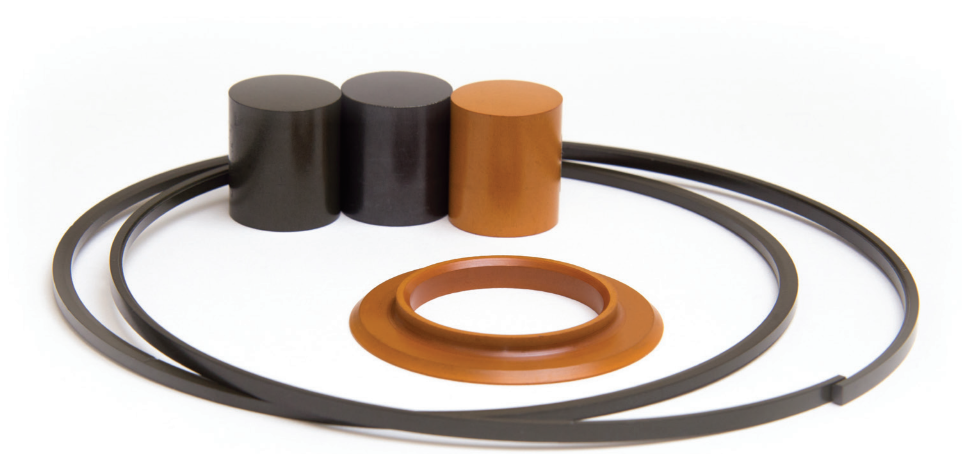
Source: McDonald and Rao (1987)

Figure 3. Machined Vespel® SP-1 Polyimide Apparent Modulus vs. Time with Various Loads and Temperatures



Machined Vespel® SP-1 maintains much of its apparent modulus over time, even with high loads and elevated temperatures.

Source: DuPont™ (1993)

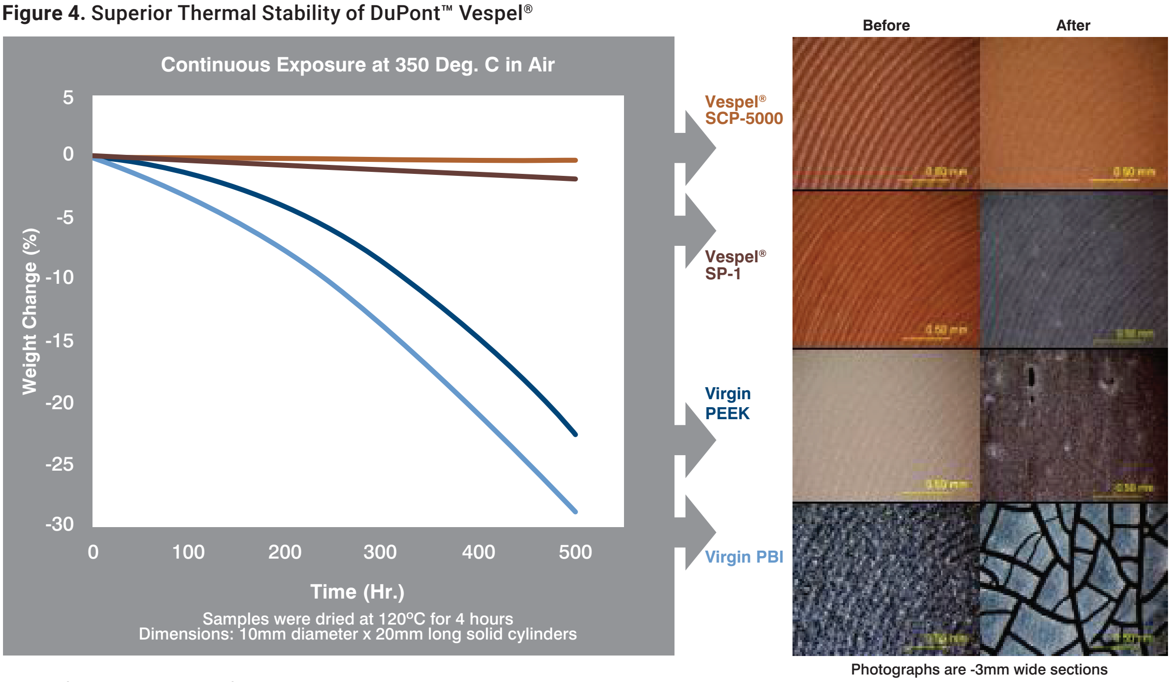


THERMAL STABILITY

Thermal stability describes a polymer's ability to resist degradation when exposed to elevated temperatures over long periods of time. DuPont™ Vespel® has superior thermal stability compared with many other high performance plastics.

Figure 4 shows test coupons of Vespel® SP-1, Vespel® SCP-5000, PEEK (polyetheretherketone), and PBI (polybenzimidazole) exposed to 350°C for 500 hours. Note that both grades of DuPont™ Vespel® exhibited negligible weight loss and the samples maintained their integrity. Under the same conditions, both PEEK and PBI showed signifigant weight loss and drastic changes in appearance.

Figure 4. Superior Thermal Stability of DuPont™ Vespel®



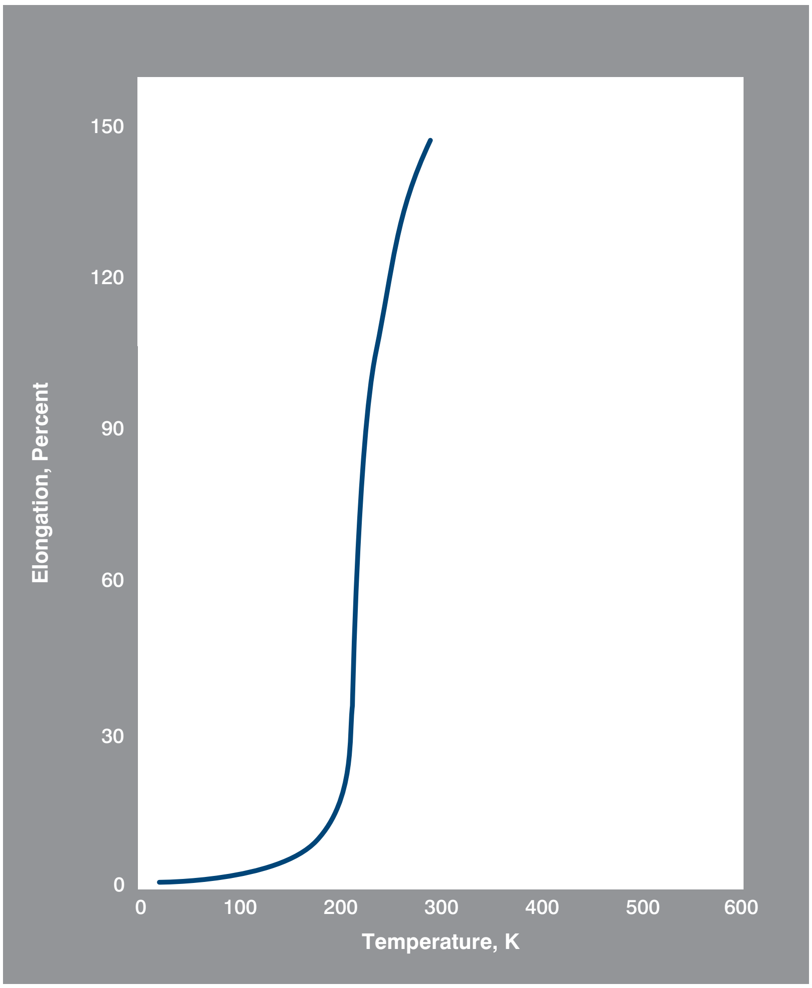
Vespel® SP-1 and Vespel® SCP-5000 exhibit superior thermal stability compared with other high performance plastics.

Source: DuPont™

COLD TEMPERATURE PERFORMANCE

Valves that operate high in the atmosphere, in space, or in polar climates may be exposed to extremely cold temperatures. Engineering thermoplastics tend to become hard and brittle at low temperatures. This presents a challenge for seal designers since plastic materials that exhibit conformability, compressibility, and high elongation at room temperature may be unsuitable for low temperature sealing applications. Figure 5 shows the tensile elongation of PCTFE (a common valve seat material) from room temperature down to 20 Kelvin. At temperatures below 150 Kelvin, PCTFE loses nearly all of its elongation and it becomes quite brittle.

Figure 5. Tensile Elongation of Virgin PCTFE with 55% Crystallinity at Various Temperatures

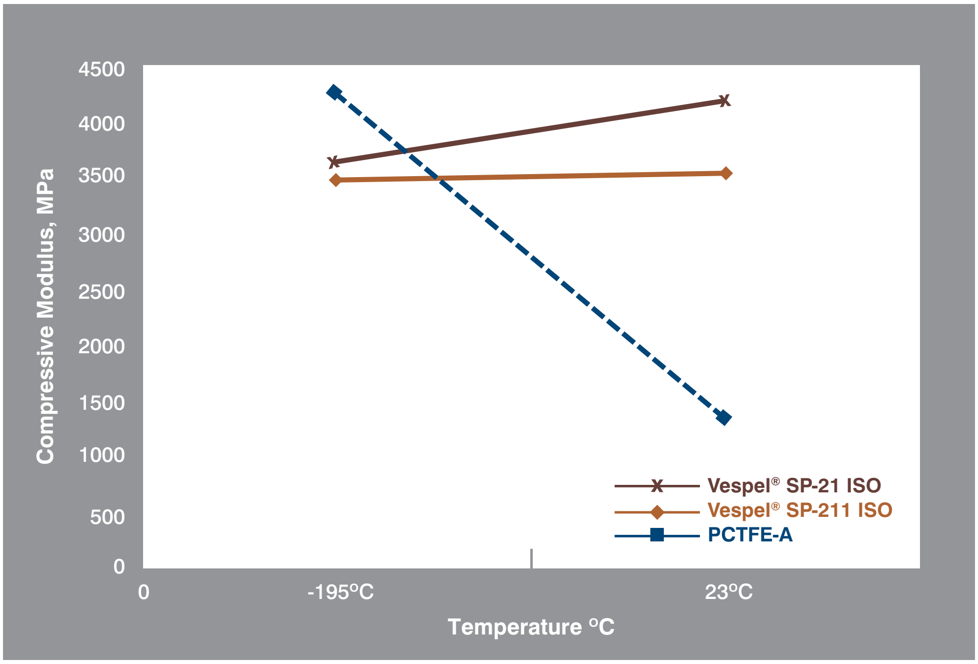


PCTFE loses much of its elongation and becomes brittle at temperatures below 150 Kelvin (-190˚F)

Source: Schramm (1973)

Figure 6 demonstrates the consistent compressive modulus of DuPont™ Vespel® parts & shapes throughout a wide temperature range compared with the more variable stiffness of PCTFE. Note that at room temperature, PCTFE is softer than DuPont™ Vespel® parts & shapes and at -195°C, PCTFE is stiffer than Vespel®. This variability complicates valve design since the degree to which PCTFE will easily conform to mating metal surfaces varies widely as a function of temperature. In contrast, the compressive modulus of Vespel® is nearly constant throughout this temperature range.

Figure 6. Compressive Modulus vs. Temperature Per ASTM D695

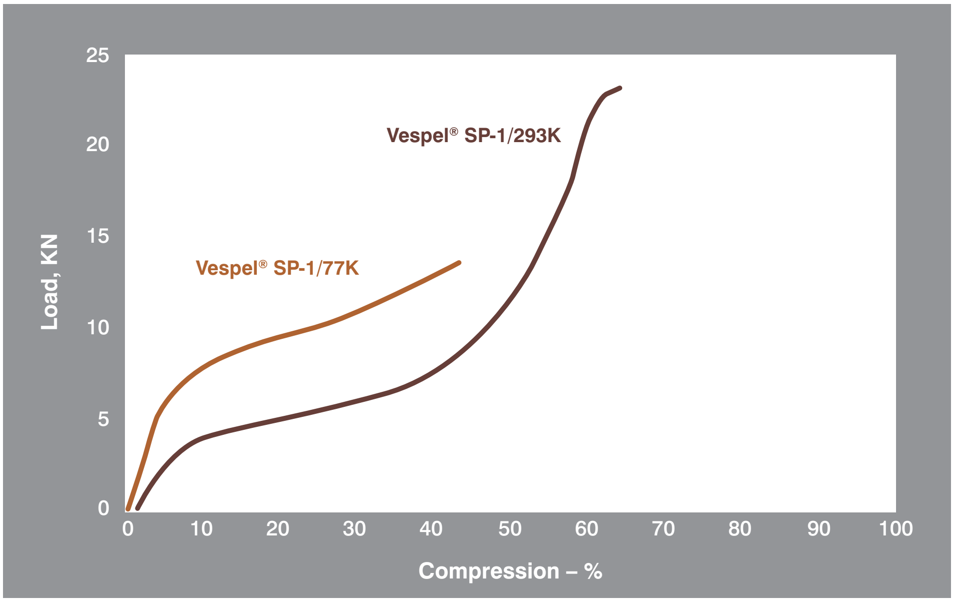


DuPont™ Vespel® vs. Virgin PCTFE at Cryogenic Temperatures
Unlike many thermoplastics such as PCTFE, DuPont™ Vespel® maintains consistent compressive modulus when cooled to cryogenic temperatures.

Source: Lewis (2015)

Figure 7 illustrates the benefit of DuPont™ Vespel® seals for valves that must operate in cold temperature environments. When put under a compressive stress, Vespel® SP-1 compressed over 60% at room temperature and over 40% at 77 Kelvin. This ability to deform ductility at extremely cold temperatures is important for low temperature applications. A valve seat or seal needs to press tightly against a mating metal surface to create a high pressure seal without experiencing brittle fracture.

Figure 7. Compressive Stress and Compressive Strain of Vespel® SP-1 at 77K and 293K



Unlike most thermoplastics, Vespel® SP-1 remains ductile at cryogenic temperatures. The material can compress over 40% at 77K.

Source: McDonald and Rao (1987)

FRICTION AND ACTUATION TORQUE

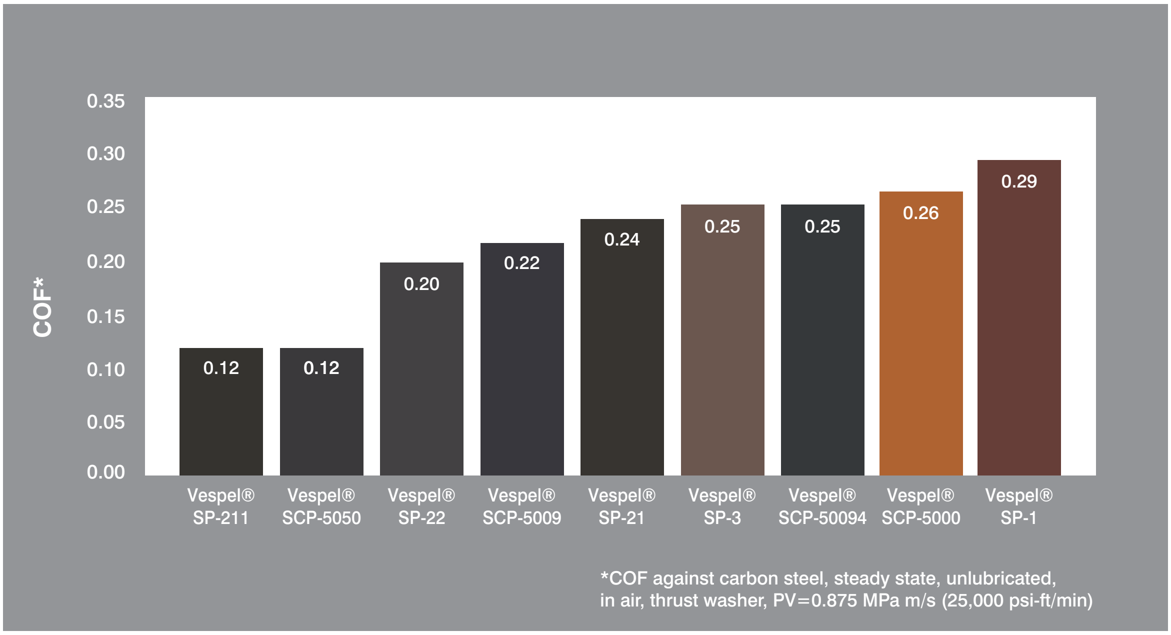
Various grades of DuPont™ Vespel® have different coefficients of friction. This allows designers to customize the level of torque required to actuate a valve. Lower friction materials have the added benefit of allowing for smaller, lighter, and less expensive actuator components. DuPont™ Vespel® does not require external lubrication and it resists "seize-up" that can occur with metal on metal sealing systems. DuPont™ Vespel® seals are resistant to abrasion by metal or dirt particles in hydraulic oil.

DUPONT™ VESPEL® GRADES AND COEFFICIENT OF FRICTION

Vespel® SP-21 and SP-22 contain graphite, which lowers their coefficients of friction and improves their dimensional stability. Vespel® SP-211 contains graphite and PTFE, which gives this grade the lowest COF of all of the DuPont™ Vespel® SP grades.

For valves and seals operating in dry or vacuum environments, Vespel® SP-3 is commonly used. The molybdenum disulfide filler in Vespel® SP-3 provides a low coefficient of friction in dry or vacuum conditions with minimal abrasion to mating surfaces. Figure 8 shows the coefficients of friction for various grades of DuPont™ Vespel®.

Figure 8. Coefficient of Friction of Vespel® SP and SCP Grades



DuPont™ Vespel® is available in formulations that have a range of coefficients of friction. DuPont™ Vespel® SP-211 is the grade with the lowest coefficient of friction at temperatures below 300° F and pressure velocity conditions of ≤ 100,000 psi-ft/min.

Source: DuPont™

OXYGEN COMPATIBILITY

Certain grades of DuPont™ Vespel® are compatible to some extent with liquid and gaseous oxygen. The National Aeronautics and Space Administration tested Vespel® SP-21 and found that it meets MSFC-SPEC-106B, “Testing Compatibility of Materials for Liquid Oxygen Systems” with approval on a selected-lot basis [1]. The U.S Naval Air Engineering Center also tested Vespel® SP-21 per MIL-V-5027C, “Non-Metallic Materials Compatible with Oxygen” and found the material to be compatible [1].

Jean-Luc Bozet and Georges Heyen from Université de Liège tested various polymers including DuPont™ Vespel® for oxygen compatibility for space propulsion applications [2]. They concluded that Vespel® SP-3 and Vespel® SP-21 exhibited high auto ignition temperatures, indicating a strong tendency for these materials to be oxygen compatible. They also commented that, “Impact tests clearly state that polyimide Vespel® SP-21 is compatible in liquid oxygen”.

It is important to note that oxygen compatibility is a complex subject and readers are cautioned to carefully evaluate any polymer before specifying it for use in an oxygen system.

CHEMICAL RESISTANCE OF DUPONT™ VESPEL®

DuPont™ Vespel® materials perform well in a variety of chemical environments including many aerospace lubricants, fuels, solvents, and hydraulic fluids. Table 1 provides chemical resistance test results for Vespel® SP grades. The retained tensile strength data shown in Table 1 was developed using exposure tests similar to ASTM Method D543-67, “Resistance of Plastics to Chemical Reagents” [1].

Although laboratory test results provide useful information about the behavior of DuPont™ Vespel® in aerospace fluids, many factors can affect the resistance of DuPont™ Vespel® to chemical attack and environmental stress cracking. These include:

- Stress concentrations
- Applied loads
- Concentration of the chemical
- Operating temperature

Readers are cautioned to carefully test DuPont™ Vespel® for chemical compatibility for a particular valve seat or seal application.

Table 1. Chemical Resistance Test Results of Vespel® SP-1

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

(1) Swelling
(2) Vespel® SP-21 polyimide (15% graphite-filled)

Source: DuPont™ (1993)

DUPONT™ VESPEL® IN SPACECRAFT VALVES

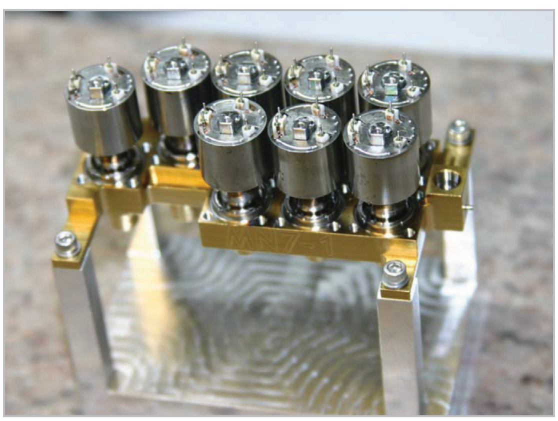
NASA scientists have done extensive qualification testing on DuPont™ Vespel®. NASA has specified DuPont™ Vespel® for use in a number of critical-service spacecraft valve applications.

Doug Wingard at the Marshall Space Flight Center conducted dynamic mechanical analysis testing of Vespel® SP-211 at extremely high temperatures [3]. He reported that, “DuPont™ Vespel® SP-211 polyimide was selected as the top candidate seal material for use in the oxidizer turbine bypass valve on NASA’s Ares I Upper Stage J-2X engine. In the OTBV, the seal material would get exposed to temperatures up to 750°F for ~10 minutes at a time.”

Anastacio Baez (1980) from NASA’s Lewis Research Center evaluated valve seat and poppet assemblies constructed from combinations of aluminum PCTFE, molybdenum disulfide-filled nylon, and DuPont™ Vespel® for use in solenoid valves for digital actuators [4]. Each combination of materials was tested for over 100 million cycles. Baez concluded that, “The graphite composite poppet in combination with a DuPont™ Vespel® seat was considered the most promising combination for use in digital electronic controls for gas turbine engines.”

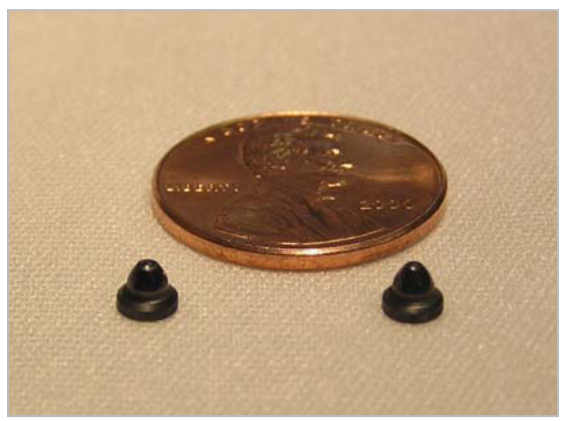
James Smith from the Marshall Space Flight Center specified Vespel® SP-22 pintle tips for the double latching solenoid valves on the Mars instrument suite [5]. The valves had to operate reliably with a maximum helium leak rate of less than $1x10^{-10}$ atm.cc/sec. with a qualification temperature range of -60°C to +225°C and an operating temperature range from -40°C to +195°C. Photographs of the microvalves and the pintle tips are shown below.

These examples illustrate how DuPont™ Vespel® has been qualified by NASA for use in a number of different high-performance spacecraft valve applications.



Flight Microvalves Welded into a Flight Manifold

Source: Smith (2008)



Pintle Tips

Source: Smith (2008)

SUMMARY

This paper has provided an overview of the benefits of DuPont™ Vespel® for aerospace valve seats and seals.

These benefits include:

- Low and consistent rates of thermal expansion and contraction.
- Moderate compressive modulus and ductile behavior throughout a broad temperature range.
- Excellent resistance to creep and stress relaxation.
- Grades available with low to moderate coefficients of friction to allow for specific actuation torques.
- Grades available for use in vacuum sealing applications.
- Certain grades exhibit some degree of oxygen compatibility.

For More Information

Contact Curbell Plastics for more detailed information on any of the topics discussed in this paper. For technical inquiries regarding DuPont™ Vespel® parts & shapes or any of our other high performance plastics you can contact the authors of this paper or use our online Ask a Plastics Expert form.

ABOUT AUTHENTIC DUPONT™ VESPEL® SHAPES

Curbell Plastics is an authorized distributor of Authentic DuPont™ Vespel® polyimide shapes (rod, plaque, bar, balls).

What purchasing Authentic DuPont™ Vespel® from an authorized distributor means for you.

When you purchase DuPont™ Vespel® from Curbell Plastics for your aerospace, semiconductor manufacturing, and machine shop high performance parts it will be labeled with a genuine DuPont™ Vespel® shapes product label and be accompanied by an official Certificate of Conformance (CoC). It will also contain a tamper-evident product label that is serialized to add a level of traceability and contain covert security technology that helps prevent the counterfeiting of Authentic DuPont™ Vespel® shapes product labels.

DuPont has granted Curbell Plastics permission to legally reproduce the original CoC to accompany purchased Authentic DuPont™ Vespel® shapes cut to length. This product certification is non-transferable and is valid only to the first end-user purchasing from Curbell Plastics, a DuPont authorized distributor.
Product and/or product certification obtained from an unauthorized source is assumed counterfeit. DuPont makes no warranties and assumes no liability in connection with the use of product or product certification obtained from an unauthorized source.

DUPONT™
Authorized Distributor

REFERENCES

[1] DuPont (1993). Properties of DuPont Vespel® parts. DuPont publication H15824-1.

[2] Bozet J., Heyen, G., Dodet, C., Duquenne, M., & Kreit, P. (2011). Liquid oxygen compatibility of materials for space propulsion needs. Presented at the 4th European Conference for Aerospace Sciences (EUCASS).

[3] Wingard, D. (2013). Dynamic mechanical analysis (DMA) to help characterize Vespel® SP-211 polyimide material for use as a 750 °F valve seal on the Ares I upper stage J-2X engine. Proceedings of the 41st Annual Conference of the North American Thermal Analysis Society. Bowling Green, Kentucky, 4-7 August 2013.

[4] Baez, A. (1980). Durability tests of solenoid valves for digital actuators. NASA Technical Memorandum 81522.

[5] Smith, J. (2008). Design and development of a miniaturized double latching solenoid valve for the sample analysis at Mars instrument suite. Proceedings of the 39th Aerospace Mechanisms Symposium, NASA Marshall Space Flight Center, May 7-9, 2008.

Figure 1:

DuPont (1993). Properties of DuPont™ Vespel® parts. DuPont publication 233630A.
McKeen, L. (2008). The effect of temperature and other factors on plastics and elastomers, second edition. Norwich, NY: William Andrew.

Figures 2 and 7:

McDonald, P. & Rao, M. (1987). Thermal and mechanical properties of Vespel® at low temperatures. Proceedings from the International Cryogenic Materials Conference, Saint Charles, IL, 14-18 June, 1987.

Figure 3:

DuPont (1993). Properties of DuPont™ Vespel® parts. DuPont publication 233630A.

Figures 4 and 8:

DuPont™ laboratory test results

Figure 5:

Schramm, R., Clark, A., & Reed, R., (1973). A compilation and evaluation of mechanical, thermal, and electrical properties of selected polymers. National Bureau of Standards monograph 132. Washington, DC: U.S. Government Printing Office.

Figure 6:

Lewis, G., Merot, P., & Matoux, J. (2015). High performance polyimide parts can help reduce actuation torque and improve sealing in cryogenics ball valves for LNG (Liquid Natural Gas) applications. Presented at the AMI International Conference on Oil & Gas Non-Metallics. London. December 8-10, 2015.

Table 1:

DuPont (1993). Properties of DuPont™ Vespel® parts. DuPont publication 233630A.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Scott Stenta from DuPont for providing laboratory data and technical advice for this publication.

ABOUT THE AUTHORS

Ryan Nelson is a Regional Sales Manager for Curbell Plastics. He has over 10 years of experience working with the engineering community on plastic material selection and plastic part design, with an emphasis on identifying the right grades of DuPont™ Vespel® for aerospace, semiconductor, and scientific instrumentation applications.

rnelson@curbellplastics.com | **623-907-5240 x6578**

Dr. Keith Hechtel is Senior Director of Business Development for Curbell Plastics. Much of his work involves helping companies to identify plastic materials that can be used to replace metal components in order to achieve quality improvements and cost savings. Dr. Hechtel has over 30 years of plastics industry experience and he is a recognized speaker on plastic materials and plastic part design.

khechtel@curbellplastics.com | **716-740-9142**

Connect with Dr. Hechtel on LinkedIn.

TECHNICAL EXPERTISE

Curbell white papers are intended to provide engineers and designers with basic information about the engineering polymers available as sheet, rod, tube, and film stock from Curbell Plastics. We invite you to contact Curbell via e-mail at **technicalsupport@curbellplastics.com** to discuss applications in detail.

ABOUT CURBELL PLASTICS

For 76 years, Curbell Plastics has been one of the nation's leading providers of plastic sheets, rods, tubes, and films, as well as fabricated parts, adhesives, and prototyping materials. Our customers range from small local businesses to large *Fortune* 500 companies and government agencies. We partner with organizations in dozens of industries, including aerospace, pharmaceutical, machinery manufacturers and sign fabricators. At Curbell, we understand the unique demands of each market and we have the expertise to help you meet your business needs. Whether your objective is to reduce manufacturing costs, improve productivity, or increase product reliability, Curbell can help.

OUR CAPABILITIES

Our branch network includes sales and warehouse locations throughout the United States. We offer a number of value-added services including custom cutting, fabrication, packaging, and kitting, as well as warehousing for just-in-time delivery. With Curbell, you get the plastics you want and the peace of mind you need, from technical support and design assistance at the earliest stages of product design, through production and after-sale support for each product we sell.

PUT US TO WORK FOR YOU

At Curbell, we are committed to providing the highest level of service to our customers. We recognize the urgency of customer needs, and we pride ourselves on providing quick and proactive solutions. Our tag line says it all – we appreciate the opportunity to earn your business and we invite you to ***"Put us to work for you!™"***

Curbell Plastics, Inc.
7 Cobham Drive
Orchard Park, NY 14127
1-888-CURBELL
www.curbellplastics.com

CURBELL PLASTICS