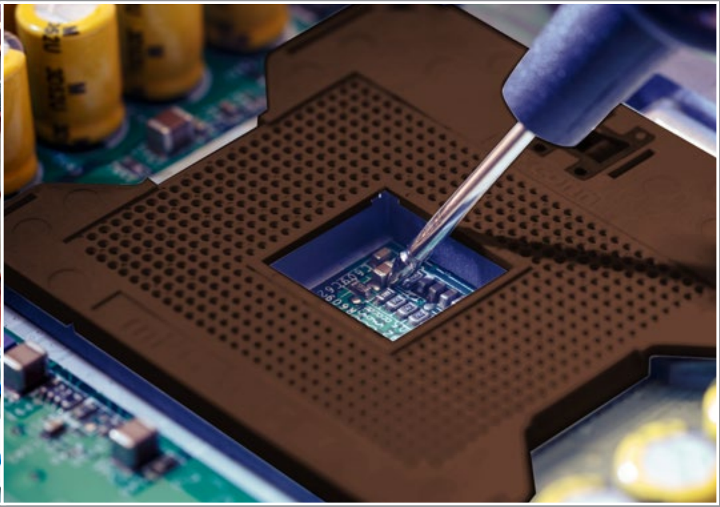
10 BENEFITS OF DUPONT™ VESPEL® PARTS AND SHAPES FOR DEMANDING APPLICATIONS



Curbell Plastics, Inc.
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DuPont™ Vespel® materials have properties that allow them to perform under extreme conditions, where other plastics and composites would quickly fail.

DuPont™ Vespel® materials are often specified for aerospace, military, and semiconductor applications where performance and reliability are essential. These unique plastics have properties that allow them to perform under extreme conditions, where other plastics and composites would quickly fail.

The purpose of this article is to describe 10 benefits of Vespel® that are relevant for a wide range of applications. The references listed at the end provide sources of information for those wishing to develop a richer understanding of Vespel® materials.

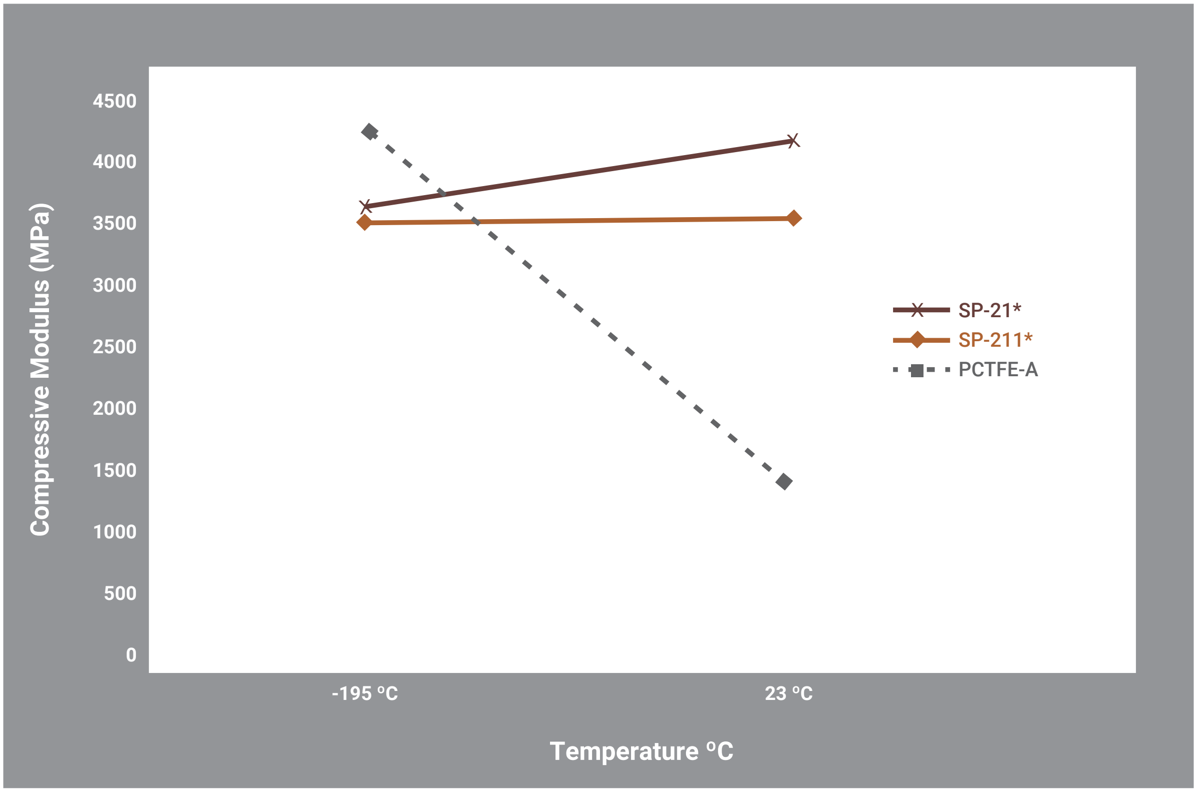
1. CONSISTENT, MODERATE MODULUS

Plastics are often specified for seals, bearings, and material handling devices due to their moderate compressive modulus (stiffness). For these mechanisms to function properly, the polymer components must be soft enough to function in contact with mating metal parts without damaging them and yet stiff enough to support mechanical loads. For example, a plastic valve seal needs to be soft enough to conform to irregularities in mating metal surfaces to prevent leak paths and also stiff enough to seal a pressurized process fluid.

This “Goldilocks” compressive modulus (not too soft and not too stiff) is often in the range of 2000 to 3000 MPa. These are typical values for many engineering plastics at room temperature including nylon 66, acetal copolymer, and Vespel® SP-1.

Devices intended for use in extreme service conditions may be required to function throughout a wide operating temperature range, in some cases from cryogenic conditions to elevated temperatures. Many engineering plastics become stiff and brittle at cold temperatures and soft, with greatly reduced strength and modulus at elevated temperatures, making them unsuitable for these applications. Vespel® offers the advantage of maintaining much of its room temperature ductility at low temperatures and also having substantial strength and modulus at elevated temperatures. Figure 1 illustrates this.

Figure 1. Compressive Moduli of PCTFE, Vespel® SP-21, and Vespel® SP-211 at Various Temperatures



**Properties shown are for ISO molded shapes*
Source: Adapted from Lewis, G., Merot, P., & Matoux, J. (2015). Provided courtesy of DuPont™.
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The graph shows the compressive moduli of PCTFE (polychlorotrifluoroethylene), Vespel® SP-21, and Vespel® SP-211 at temperatures from -195 °C to 23 °C. Throughout this temperature range, the modulus of PCTFE varies from 4275 MPa at -195 °C to 1370 MPa at room temperature. PCTFE's stiffer behavior at lower temperatures limits the material's ability to conform to irregularities in mating metal surfaces. PCTFE's higher modulus at cold temperatures also increases actuation torque for valves where the polymer seal functions as friction and wear surfaces during actuation. The lower modulus of PCTFE at elevated temperatures may limit the material's ability to maintain a seal with a pressurized process fluid. In contrast, Vespel® SP-21 and Vespel® SP-211 maintain consistent compressive moduli, and correspondingly consistent performance, throughout the temperature range shown on the graph.

2. CREEP AND STRESS RELAXATION RESISTANCE

Plastics are viscoelastic materials that respond to long-term mechanical stresses via creep strain (deformation) and/or stress relaxation (a part in a constrained state under load exhibiting a gradual reduction in stress while the shape of a part remains unchanged). Both creep and stress relaxation are more pronounced at higher loads and at elevated temperatures.

Resistance to stress relaxation is particularly important in applications such as seals and the polymer locking elements in mechanical fasteners since loss of stress can prevent these components from functioning properly. Stress relaxation in a locking fastener can reduce the anti-loosening characteristics of the fastener. Examples of mechanical fasteners with polymer locking elements are shown in the photo below.

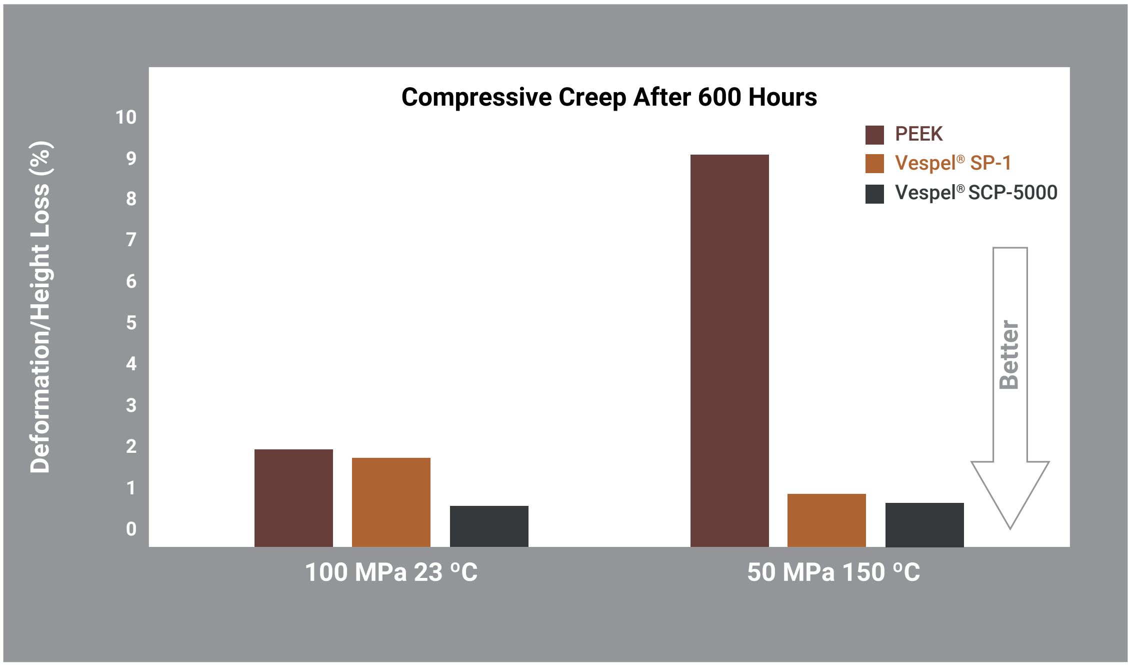
Vespel® locking elements in mechanical fasteners.

Stress relaxation in a seal can result in leak paths. An example of a pipe flange with a plastic seal that failed due to stress relaxation is shown in the photo below.

Pipe flange with a polymer seal that failed due to stress relaxation.

Vespel® has excellent resistance to creep and stress relaxation, which makes it the material of choice for seals and locking fasteners in demanding industries such as aerospace, spacecraft, and semiconductor. Figure 2 shows the compressive creep characteristics of Vespel® SP-1, Vespel® SCP-5000, and PEEK at various stresses and temperatures. The graph illustrates the low creep strain (long-term deformation) of Vespel® compared with PEEK, especially at high loads and elevated temperatures.

Figure 2. Creep Strain of Vespel® SP-1, Vespel® SCP-5000, and PEEK



Source: Chickola, J., Jackowiak , R., & Liekens, P. (2024). Provided courtesy of DuPont™.
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Table 1 and Figure 3 illustrate important compressive property and stress relaxation advantages of Vespel® SP-1 compared with PCTFE (polychlorotrifluoroethylene) and PAI (polyamide-imide).

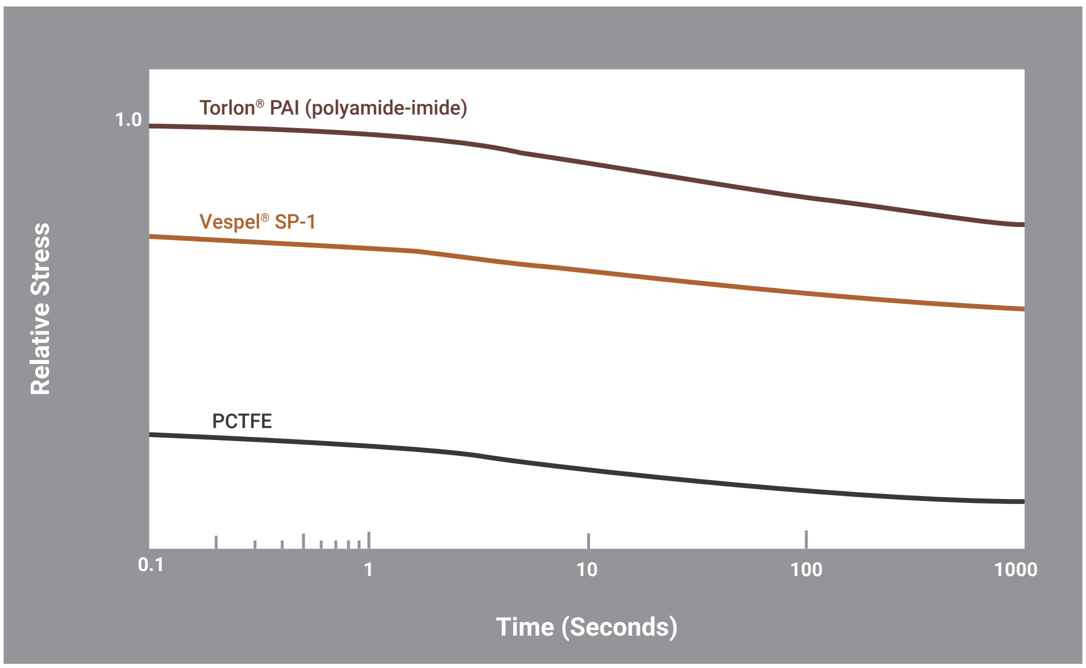
Table 1. Compressive Moduli of PCTFE, Vespel® SP-1, and PAI at Room Temperature

	PCTFE	Vespel® SP-1	Torlon® PAI
Compressive Modulus per ASTM D-695 (MPa)	1370	2413	3296

As previously noted, Vespel® SP-1 exhibits moderate compressive modulus, which is ideal for many sealing applications. PCTFE is softer (lower compressive modulus), which allows it to more easily conform to irregularities in mating surfaces, but PCTFE may be too soft to prevent leak paths in some high pressure sealing applications. Torlon® PAI (polyamide-imide) is an extremely strong and stiff material, with high compressive modulus. Because of its high modulus, Torlon® may not easily conform to imperfections in mating metal surfaces, resulting in leak paths for some sealing applications. Vespel® has a compressive modulus of 2413 MPa, which allows it to easily conform to mating surfaces while also having sufficient mechanical strength to maintain a seal for many applications that involve pressurized process fluids.

Figure 3 compares the stress relaxation characteristics of PCTFE, Torlon® PAI, and Vespel® SP-1 in 10% compression at 299 Kelvin (26 °C). At 10% compressive strain, Vespel® SP-1 exhibits compressive stress higher than PCTFE and lower than Torlon®. Once again, demonstrating the "Goldilocks" compressive modulus, with Vespel's® modulus falling in between the softer PCTFE and the stiffer Torlon®. The graph also shows that Vespel® SP-1 has excellent stress relaxation resistance, maintaining much of its initial stress at 1000 seconds.

Figure 3. Stress Relaxation of Vespel® SP-1, Torlon® PAI, and PCTFE in Compression at 10% Engineering Strain at 299 K



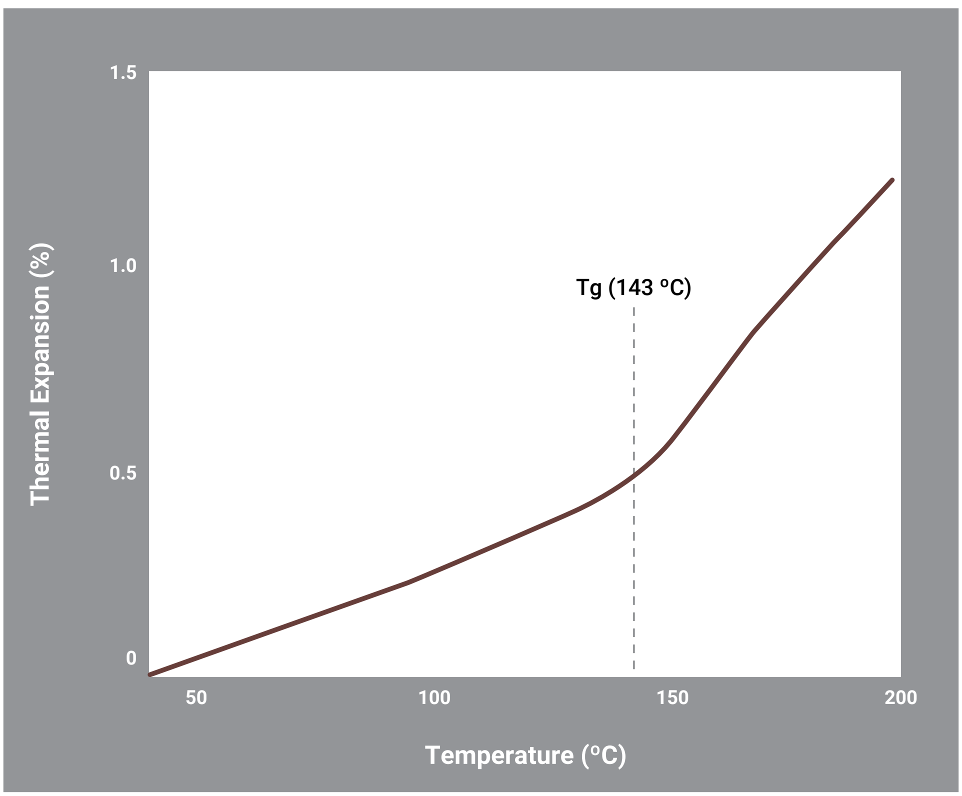
Source: Adapted from Wylie, K., Hockett, J., and Buxton, T., (1981)

3. CONSISTENT CTE (COEFFICIENT OF THERMAL EXPANSION)

Plastic materials tend to have higher rates of thermal expansion compared with metals. This complicates the design of devices that include both metal and plastic components that must function throughout a wide operating temperature range. Plastic parts with high thermal expansion rates may grow when heated and shrink when cooled to an extent that prevents assemblies from functioning at the extreme ends of their operating temperature ranges.

Many thermoplastics exhibit changes in their rates of thermal expansion as the materials move through transitions, which further complicates the design problem. For example, Figure 4 shows how the thermal expansion rate of PEEK increases above its glass transition temperature.

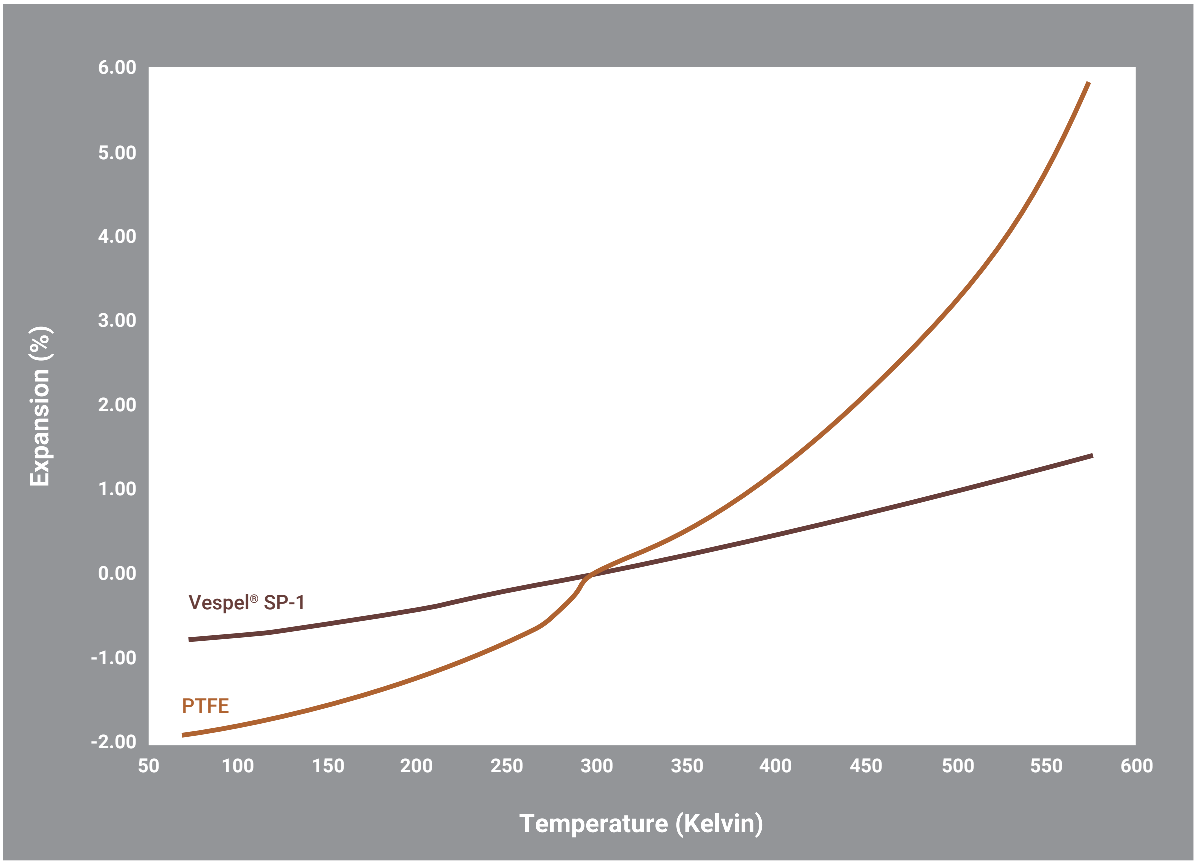
Figure 4. Thermal Expansion Curves for PEEK Both Above and Below the Material's Glass Transition Temperature



Source: Adapted from Jiang (2021)

Vespel® is unique in that it has a relatively low, consistent, and roughly linear rate of thermal expansion from cryogenic temperatures up to 250 ºC. Filled grades of Vespel® have lower rates of expansion compared with unfilled grades. Figure 5 compares the thermal expansion rates of Vespel® SP-1 and PTFE from 73 K to 573 K. Note the high and non-linear rate of thermal expansion of PTFE.

Figure 5. Linear Thermal Expansion of Vespel® SP-1 and PTFE from 73 K to 573 K



Source: Adapted from McDonald & Rao (1987), Kirby (1956), and DuPont™ (2022)

The low and nearly linear rate of thermal expansion of Vespel® is one reason that this material is so often specified for applications such as high performance seals that require plastics that are dimensionally stable throughout a broad operating temperature range.

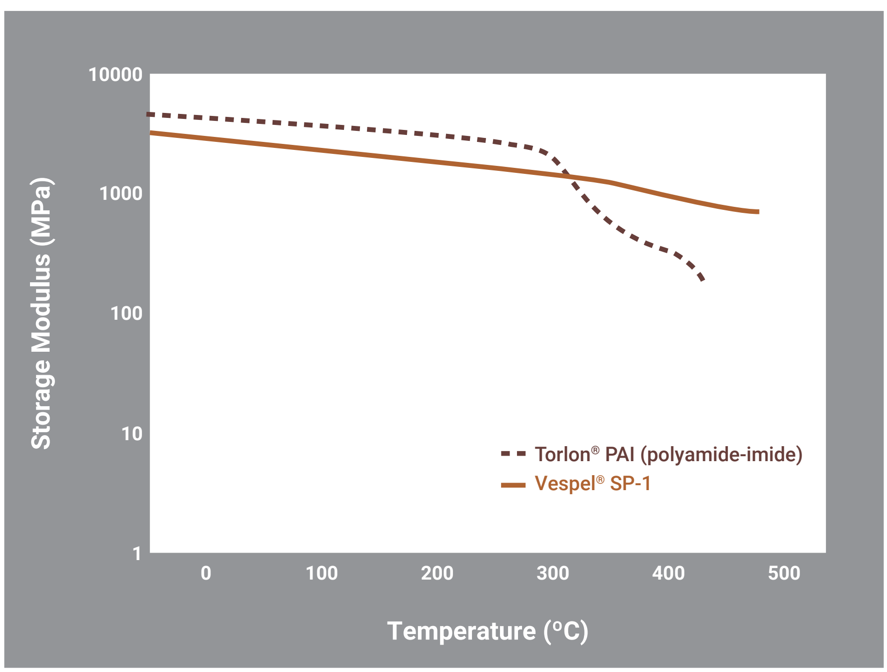
4. HIGH TEMPERATURE PERFORMANCE

High operating temperatures require plastics that have a number of key performance characteristics including:

- Sufficient strength and modulus to support mechanical loads at the required temperature
- Resistance to degradation of strength and ductility due to long-term exposure to elevated temperatures
- Resistance to creep and stress relaxation at the required temperature
- A low enough rate of thermal expansion so that the plastic part will have sufficient dimensional stability

Vespel® provides exceptional performance in high temperature applications. Figure 6 compares the storage modulus (stiffness) of Vespel® SP-1 and Torlon® PAI at elevated temperatures. It is important to note that the Y axis of the graph, storage modulus, is a logarithmic scale. Torlon® is stiffer than Vespel® SP-1 at temperatures lower than 325 °C and softer than Vespel® SP-1 at temperatures higher than 325 °C. Vespel® SP-1 exhibits a more consistent modulus than Torlon® throughout the temperature range shown on the graph.

Figure 6. Storage Modulus of Vespel® SP-1 Compared with Torlon® PAI



Source: Kane (2004). Provided courtesy of DuPont™.
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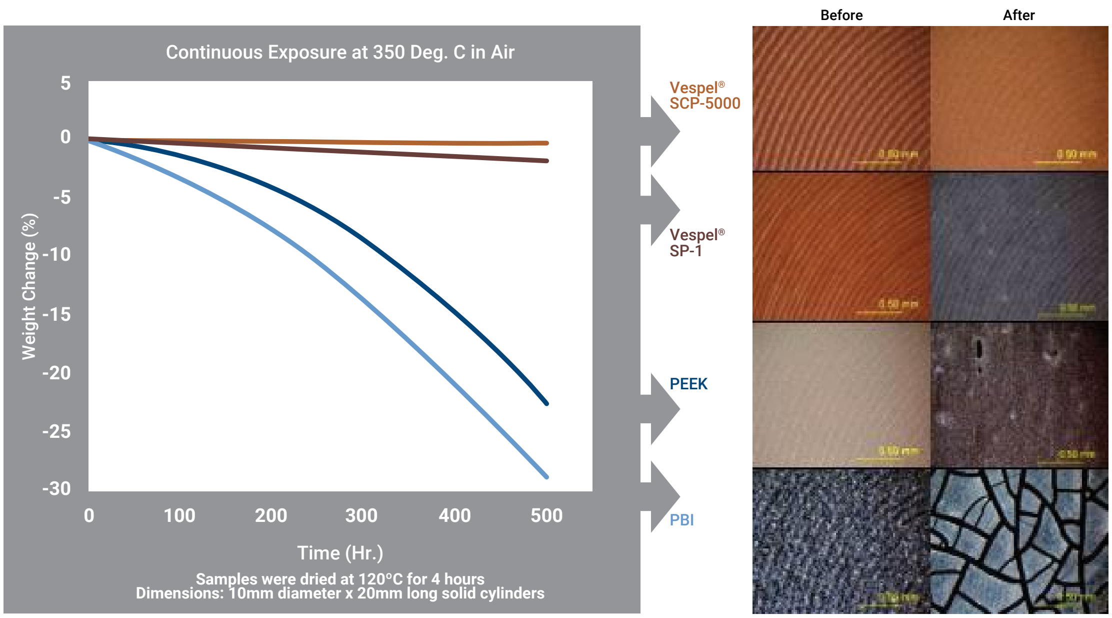
Figure 7 illustrates Vespel's® resistance to degradation at elevated temperatures. Vespel® SP-1 and Vespel® SCP-5000 are compared with PEEK and PBI (polybenzimidazole) for resistance to thermal degradation when heated to 350 ºC for a period of 500 hours. Both grades of Vespel® exhibit significantly less weight loss and less change in appearance when compared with the other two polymers.

Figure 7. Resistance to Degradation at Elevated Temperatures for Vespel® SP-1, Vespel® SCP-5000, PEEK, and PBI



Source: Hechtel & Loudin (2013). Provided courtesy of DuPont™.
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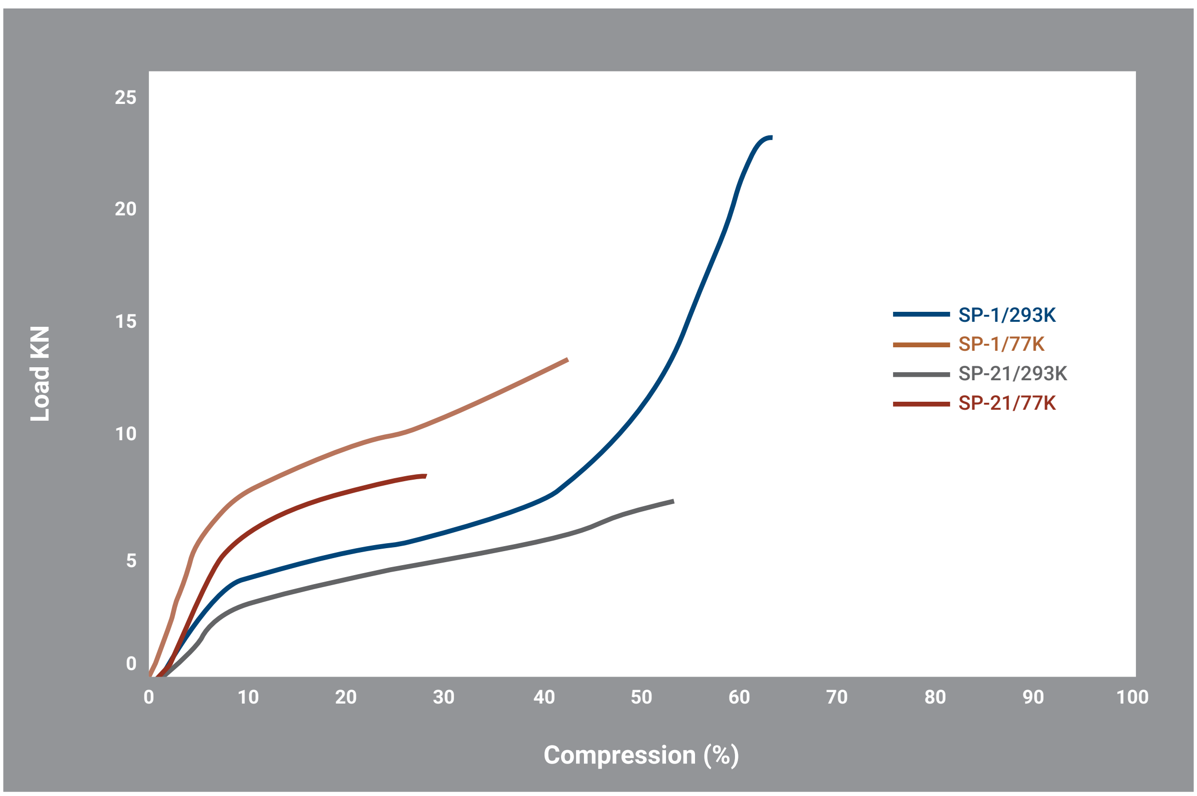
Vespel's® resistance to degradation at elevated temperatures and its consistent modulus throughout a broad operating temperature range makes it an ideal choice for many demanding high temperature applications.

5. LOW TEMPERATURE PERFORMANCE

Devices that must operate at low temperatures often require plastic materials that maintain ductility throughout the required temperature range. Additionally, a low and consistent rate of thermal contraction may be required so that the part will maintain its dimensions within specified tolerances.

Figure 8 shows that Vespel® SP-1 and SP-21 exhibit ductile behavior in compression at 77 Kelvin (-196 °C). Most plastic materials become brittle in cold temperatures, making them unsuitable for applications that require ductility in cryogenic conditions.

Figure 8. Ductile Compressive Strain of Vespel® SP-1 and SP-21 at 77 and 293 Kelvin



Source: McDonald & Rao (1987)

For some cold temperature applications, materials with low thermal conductivity are required. Vespel® materials have extremely low thermal conductivity at cryogenic temperatures, making them ideal for use as thermal isolators. Table 2 below shows the thermal conductivities of Vespel® SP-1, Vespel® SP-22, and various other plastics and composites at cryogenic temperatures.

Table 2. Thermal Conductivities of Various Plastics and Composites at Cryogenic Temperatures

Material	Thermal Conductivity @ 0.3 K (mW/m K)	Thermal Conductivity @ 1.4 K (mW/m K)	Thermal Conductivity @ 4.2 K (mW/m K)
Vespel® SP-1 (unfilled)	0.553	3.21	9.74
Vespel® SP-22 (40% graphite filled)	0.217	2.46	14.3
PEEK	1.00	5.31	12.0
PEEK (30% carbon fiber filled)	0.823	4.66	10.6
PEEK (30% glass filled)	0.812	6.20	19.6
Pulltruded Glass/Epoxy Rod	1.08	17.8	73.2
Torlon® 4301	1.06	11.8	28.5
G-10/FR-4	1.64	20.6	65.6

Source: Adapted from Runyan, M., & Jones, W., (2008)

Outstanding cold temperature ductility, a low rate of thermal contraction, and low thermal conductivity make Vespel® the material of choice for bearings, seals, and thermal isolators that operate in cold environments.

6. RADIATION RESISTANCE

Exposure to radiation causes color shift and loss of tensile strength and tensile elongation (ductility) in most engineering plastics. Polyimide materials such as Vespel® generally exhibit superior resistance to degradation from gamma and electron beam radiation exposure compared with many other plastic materials.

7. VACUUM COMPATIBILITY

Applications in spacecraft, scientific instrumentation, and semiconductor manufacturing may require devices to perform in vacuum conditions. This requires plastics with low outgassing and for some applications, the ability to achieve vacuum seals. Mechanisms that involve sliding contact between a polymer part and a metal part in vacuum may require the sliding pair to have a low coefficient of friction and a low wear rate without the use of external lubrication.

Table 3 shows the outgassing characteristics of Vespel® SP-1 compared with Nylon 6 as reported by NASA's low outgassing database.

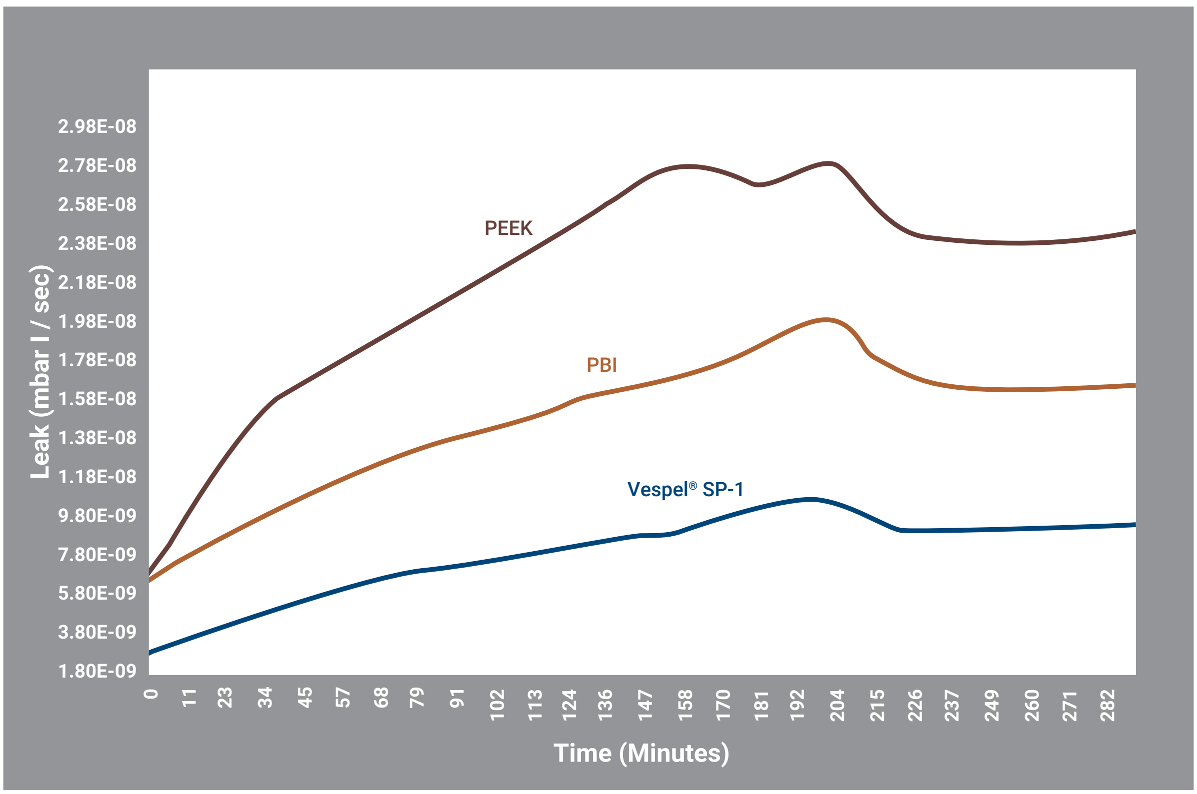
Table 3. Outgassing Characteristics of Vespel® SP-1 and Nylon 6

	Vespel® SP-1	Nylon 6
Total Mass Loss (TML) per ASTM E595 (%)	1.04	3.4
Collected Volatile Condensable Materials (CVCM) per ASTM E595 (%)	0.00	0.17

Source: NASA

Vespel® SP-1 also has superior vacuum sealing characteristics compared with many other high performance polymers. Figure 9 shows the results of vacuum seal testing by measuring helium permeation into vacuum chambers sealed with PEEK, PBI (polybenzimidazole) and Vespel® SP-1. Vespel® SP-1 has a lower leak rate compared with the other two polymers, indicating superior vacuum sealing performance.

Figure 9. Vacuum Sealing Characteristics of Vespel® SP-1, PBI, and PEEK Measured via Helium Permeation at Room Temperature



Source: Adapted from Murari & Barzon (2004)

Vespel® SP-3, which has the dry lubricant molybdenum disulfide in its formulation, has outstanding friction and wear characteristics against many metal materials in vacuum conditions.

8. FRICTION AND WEAR PROPERTIES

Friction and wear are system properties, that involve a plastic material in direct sliding contact with a metal counterface. For these applications, the coefficient of friction and the wear rate will depend on a number of factors including:

- The base polymer
- The additives in the plastic formulation
- The presence or absence of water, oil, or other lubrication
- The presence or absence of abrasive particles
- Mechanical loads
- The relative velocity of the two surfaces
- The chemistry, hardness, and surface finish of the metal that the plastic will be sliding against

Due to the complexity of tribology, it is difficult to generalize about the friction and wear performance of polymers and polymer composites. That being said, friction and wear grades of Vespel® can perform in sliding wear applications where other plastics would quickly fail. The advantages of Vespel® for sliding wear include:

- Grades available with low friction and low wear rates against many metal materials without the need for external lubrication
- The ability to operate in extremely high pressure-velocity conditions where other plastics would soften and fail due to frictional heat
- Formulations available that have good friction and wear characteristics at cryogenic temperatures and at elevated temperatures
- Grades available that have low friction and long wear life in vacuum
- Grades available that reduce noise and vibration
- Grades available with high compressive strength and compressive modulus for friction and wear applications that involve high mechanical loads

Limiting pressure-velocity values represent the combination of mechanical loading and relative velocity between surfaces, above which a plastic material will rapidly fail. Table 4 shows the higher pressure-velocity capabilities of various grades of Vespel® compared with several other engineering plastics in laboratory conditions.

Table 4. Maximum Unlubricated PV Limits for Various Grades of Vespel® and Several Other Engineering Plastics Under Conditions of Continuous Motion

Material	Filler	lb-ft	kg-m	Maximum Contact Temperature	
		in²-min	cm²-sec	°F	°C
Vespel® SP-21	15% Graphite	300,000	107	740	393
Vespel® SP-22	40% Graphite	300,000	107	740	393
Vespel® SP-211	15% Graphite 10% PTFE	100,000	36	500	260
PTFE*	Unfilled	1,800	0.64	500	260
	15-25% Glass	12,500	4.5	500	260
	25% Carbon	20,000	7.1	500	260
	60% Bronze	18,500	6.6	500	260
Nylon	Unfilled	4,000	1.4	300	217
Acetal	PTFE	7,500	2.7	250	201
	Unfilled	3,500	1.2	-	-

**At 100 fpm*
***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.*
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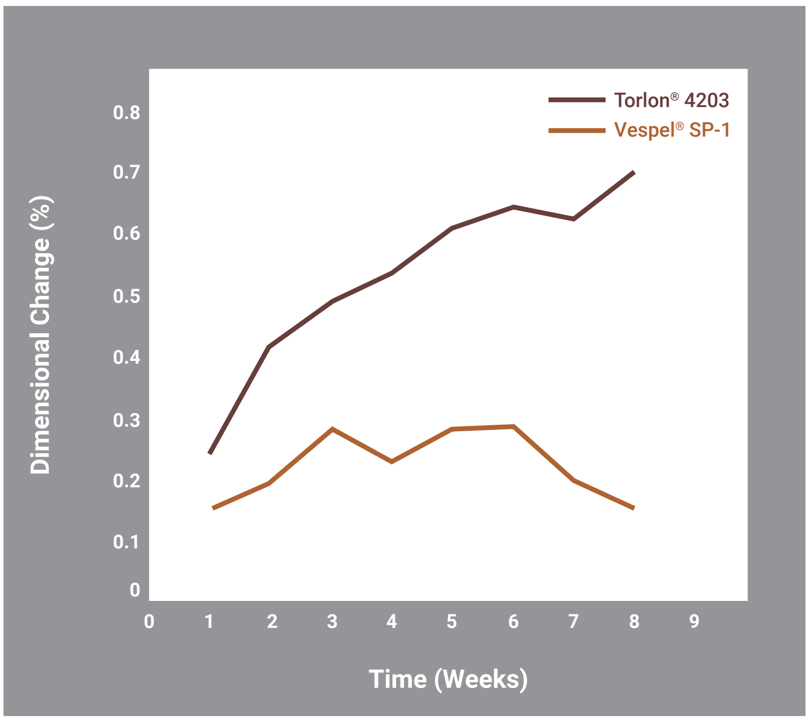
9. DIMENSIONAL STABILITY IN HUMID ENVIRONMENTS

Some plastic materials such as nylon 6/6 and Torlon® PAI (polyamide-imide) absorb significant amounts of water from the atmosphere. This results in dimensional changes, which can cause parts made from these materials to grow beyond their specified tolerances. Torlon® can continue to grow for several weeks when exposed to humid conditions, which can cause parts to go out of tolerance long after they have been measured and determined to be within specifications.

Vespel® has low moisture absorption and Vespel® materials are generally stable in humid environments. Figure 10 shows the dimensional changes due to moisture absorption for Vespel® SP-1 and unfilled Torlon® 4203 PAI. The testing was done over a period of 8 weeks at 100 °F with 90% relative humidity using 1" x 1" x 1/8" thick test coupons.

Figure 10. Dimensional Changes for Vespel® SP-1 and Unfilled Torlon® 4203 PAI Over a Period of 8 Weeks at 100 °F with 90% Relative Humidity



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The low moisture absorption and correspondingly superior dimensional stability of Vespel® makes it an ideal choice for applications that require tight dimensional tolerances in humid environments.

10. FLAMMABILITY CHARACTERISTICS / OXYGEN COMPATIBILITY

Flammability is a complicated topic and great care should be taken when selecting plastics for applications where this is a concern. Many Vespel® S and SCP grades are classified as UL 94 5VA and UL 94 V-0. Published UL yellow cards show the specific ratings for different grades of Vespel®.

Vespel® SP-21 is one of the few plastic materials that has been successfully used in spacecraft oxygen systems. Vespel® SP-21 has been tested by the National Aeronautics and Space Administration and meets MSFC-SPEC-106B, “Testing Compatibility of Materials for Liquid Oxygen Systems.” Similarly, SP-21 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.”

CONCLUSION

This paper provided an overview of some of the key performance characteristics of Vespel® materials including:

1. Consistent, moderate modulus
2. Creep and stress relaxation resistance
3. Low and consistent rate of thermal expansion
4. High temperature performance
5. Low temperature performance
6. Radiation resistance
7. Vacuum compatibility
8. Friction and wear properties
9. Dimensional stability in humid environments
10. Flammability characteristics / oxygen compatibility

This unique set of properties makes Vespel® the material of choice for bearings, seals, thermal isolators, and electrical insulators for demanding industries including aerospace, spacecraft, semiconductor machinery, and scientific instrumentation.

For more information about Vespel® materials, you can review technical data on Curbell Plastics' website, www.curbellplastics.com. For specific application questions, call 1-800-553-0335 or email the author, Dr. Keith Hechtel, at khechtel@curbellplastics.com.

ABOUT AUTHENTIC VESPEL® SHAPES

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

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

When you purchase Vespel® from Curbell Plastics for your aerospace, semiconductor manufacturing, and machine shop high performance parts, it will be labeled with a genuine 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 Vespel® shapes product labels.

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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 more than 80 years, Curbell Plastics has been one of the nation's leading providers of polymer 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.

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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!™"***

ABOUT THE AUTHOR

Dr. Keith Hechtel is Senior Director of Business Development for Curbell Plastics. Much of his work involves helping companies to identify polymer materials that can be used to replace metal components in order to achieve quality improvements and cost savings. Dr. Hechtel has over 35 years of polymers industry experience and he is a recognized speaker on polymer materials and polymer part design.

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