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**Technical Paper Series**

# **Using Advanced Materials to Improve Automotive Part Life**

**Richard Van Ryper**

DuPont

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## Abstract

Much of the progress in lengthening the service life of automobiles has relied on the use of innovative materials in new designs. Advanced technologies, such as DuPont's Vespel® parts and shapes, help automotive designers meet the challenge of ever-improving quality. Not only do parts made from these materials last longer and perform better under adverse conditions, but they have proven more cost-effective than their metal counterparts.

DuPont uses proprietary resins to produce parts and shapes that withstand three of the most important challenges to the continued operation of an automobile: high wear, high temperature, and fluid sealing. The manufacturing process is similar to that used in making powder metal parts.

The parts offer excellent wear resistance at elevated temperatures and continue to operate for long periods even when lubrication fails. They do not fail catastrophically even when local temperatures may reach 371°C (700°F). Their combination of strength and elasticity offers a compliant sealing surface against metals that outperforms metal-to-metal seals in a number of ways.

## Properties of Vespel® Parts

### Wear Resistance

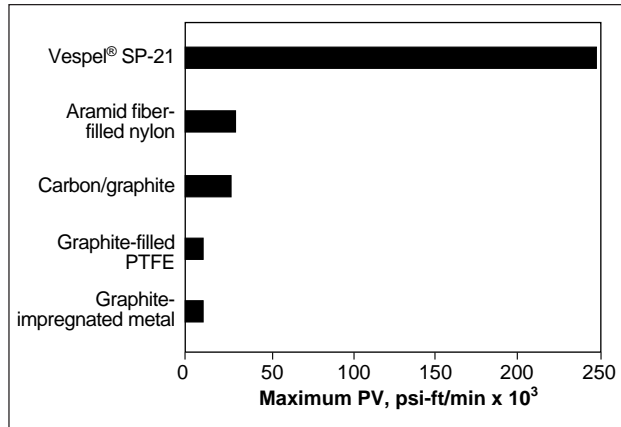
Properties can be tailored to specific applications by varying the combination of resin, fillers, and additives. For example, addition of graphite, Teflon®, or molybdenum disulfide improves the inherent lubricity and wear resistance of parts. This paper uses Vespel® SP-21 resin, a graphite-filled grade, to illustrate part performance.

In automotive applications such as transmissions, engines, and small motors, repetitive or continuous motion of materials in contact generates high friction, high temperatures, and severe abrasion.

Characterization of wear resistance always presents a problem because the phenomenon of wear is ultimately dependent on many factors: load, speed, type of motion, finishes on wear surfaces, conduction of heat away from contact areas, cross-sectional area involved, particulate contamination, and, of course, the presence of lubrication.

As a first approximation, pressure-velocity (PV) data permits the comparison of the wear properties of different materials under standard laboratory test conditions. **Figure 1** compares the wear resistance against steel of several materials in unlubricated conditions.

**Figure 1. Unlubricated Wear Resistance of Vespel® SP-21 and Other Materials**



SP-21 exhibits 10 to 100 times the unlubricated wear resistance against steel of other materials, making it a prime candidate for wear-resistant applications. The higher PV rating makes it possible to decrease the wear area relative to their metal counterparts. Reduction of contact area is important both to decrease frictional drag and to aid in reducing system size.

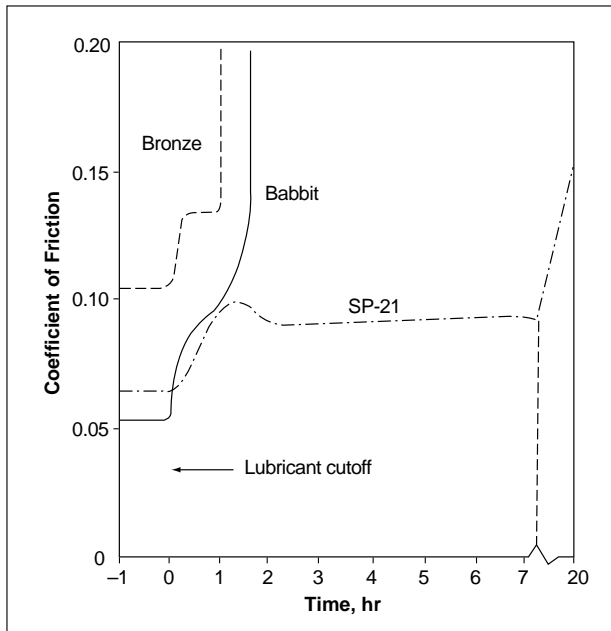
The use of lubricant films improves the PV wear performance of any material. In the case of Vespel®, PV limits as high as 2,000,000 have been achieved. Lubricants reduce friction and also conduct heat away from the wear surface (**Table 1**).

**Table 1  
Coefficient of Friction of Lubricated Bearings**

Bearing Material	Coefficient of Friction
Bronze	0.11
Babbitt	0.06
Vespel® SP-21	0.07

In many applications, the potential exists for intermittent loss of lubrication. **Figure 2** shows the advantage of using a self-lubricating material under conditions of lubricant starvation. In the illustrated case, thrust bearings made of bronze, babbitt, and SP-21 resin undergo a stepwise increase of friction when lubrication is shut off. However, the Vespel® bearing continues to operate uninterrupted, without galling or seizing, long after the metal bearings fail.

**Figure 2. Lubrication Starvation Test, Segmented Plane Thrust Bearing**



These self-lubricating materials are used extensively to replace metal in heavy-duty off-road equipment, agricultural equipment, military vehicles, and automotive mechanical assemblies, to avoid the possibility of catastrophic failure due to galling and seizing under lubricant-starved conditions.

Lubricant starvation can occur for a number of reasons (Table 2).

**Table 2  
Causes of Lubricant Starvation**

Situation	Problem
Low Temperature	Lubricant viscosity is too high to permit flow to wear surfaces
High Temperature	Lubricant viscosity is too low, causing lubricant to drain off of wear surfaces
Start-Up	Lubricant pump cannot deliver full lubrication to all surfaces simultaneously
Small or Blocked Flow Path	Inadequate lubricant delivered to wear area

In numerous applications, lubrication is either impractical or not desirable, for example in the high temperature environment of exhaust gas recirculation components. In some situations, moving parts that require protection against wear are surrounded by fluids that are poor lubricants, for example air conditioning refrigerants, brake fluid, and gasoline.

Engineers employ several technologies to compensate for the sensitivity of metals to unlubricated wear. Typically, one of the mating metal parts is chrome or tin/nickel plated, phosphate coated, ground to a fine surface finish, and/or case hardened. These processes increase part costs, require high capital cost for equipment, and often impose environmental concerns, for example the carcinogenic nature of hexavalent chromium.

Replacement of one metal part with SP-21 in a metal-to-metal wear situation can eliminate the need for special plating, coatings, extra-fine surface grinding, and metal hardening. For new parts, this can help the manufacturing plant avoid multi-million dollar capital expenditures for plating or grinding operations. Contamination of the lubricant stream causes other practical problems. Metallic wear debris or external contaminants make their way into the spaces between moving parts, increasing shaft and bearing wear. However, polymeric materials have the ability to absorb and embed hard contaminants into the wear surface, reducing damage to the adjacent metal part. There are some limitations to the use of SP-21 in wear-resistant parts, including:

- Fair wear resistance in contact with soft, nonferrous metals or soft platings such as aluminum parts or zinc-plated steel
- Higher cost than bronze, babbitt, or other specialty plastics

However, for wear resistance against ferrous metals, SP-21 offers the design engineer a number of unique performance advantages:

- High PV rating for lubricated or unlubricated applications
- Elimination of galling and seizing in lubricant-starved situations
- Wear resistance in fluids with poor lubrication qualities
- Avoiding the cost of capital equipment at manufacturing facilities for fine surface grinding, plating, and hardening
- Ability to reduce shaft wear by embedding and absorbing hard contaminants

## High Temperature Resistance

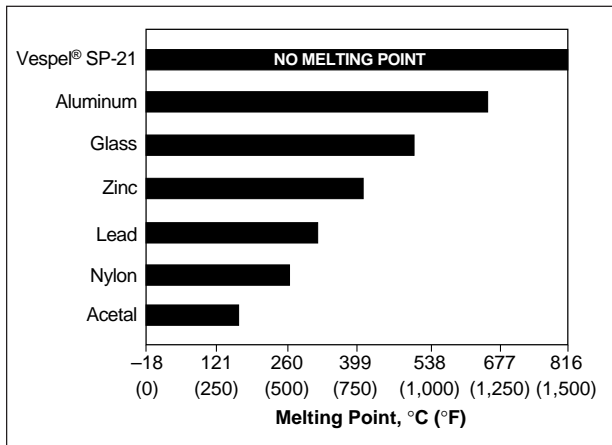
Wear-resistant applications often involve high surface temperatures because of the heat generated from friction.

SP-21 parts display temperature properties unlike those of other polymers, exceeding in some respects the performance of a number of commonly used metals. High temperature performance can be measured in a number of ways, including:

- Melting point
- Thermal degradation
- Creep
- Glass transition temperature ( $T_g$ )

Vespel® parts do not melt (**Figure 3**), although the resin degrades rapidly at 816°C (1500°F).

**Figure 3. Melting Points of Selected Materials**



Some applications that take advantage of the resistance of these parts to extreme temperatures include fixtures for handling molten glass and dies to extrude lead for lead-acid batteries. Vespel® parts can be insert molded in die-cast aluminum or zinc parts, depending on the exposure time at high temperatures.

Degradation of physical properties is a useful measure of the high temperature performance of polymers. The automotive industry uses 1,000 hr as a benchmark for the service life of parts. According to this measure, SP-21 parts would be rated at a service temperature of 316°C (600°F) (**Table 3**).

Vespel® parts can operate continuously in the range of 288–316°C (550–600°F), with excursions to 482°C (900°F), maintaining consistently high performance even when subjected to high temperatures for extended periods. In fact, after exposure

**Table 3  
Time to 50% Reduction in Tensile Strength of  
Vespel® SP-21 versus Temperature**

Temperature, °C (°F)	Time, hr
449 (840)	10
410 (770)	100
<b>316 (600)</b>	<b>1,000</b>
266 (510)	10,000

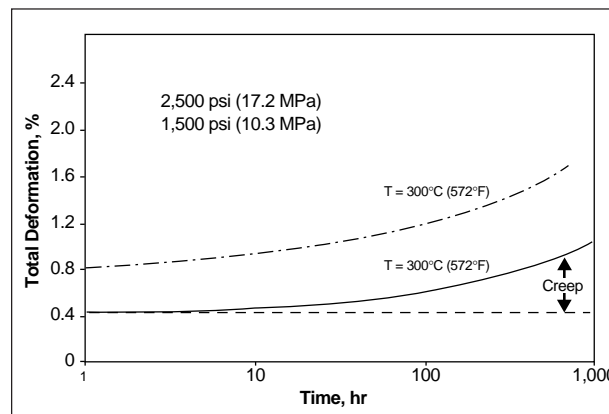
to such stressful regimes, these advanced materials behave mechanically like other high performance resins would at room temperature.

Continued exposure to conditions of 399–538°C (750–1000°F) causes microscopic surface cracks to develop, while blisters eventually form at 538°C (1000°F). Complete degradation takes place near 816°C (1500°F).

Because Vespel® does not soften and is thermally resistant, it can carry loads at temperatures beyond the capabilities of other polymers while exhibiting very low creep.

SP-21 exhibits only 0.5% creep after 1,000 hr at 300°C (572°F) and a pressure of 1,500 psi (10.3 MPa) (**Figure 4**).

**Figure 4. Total Deformation Under Load versus Time for Machined Vespel® SP-21**



Engineers often use heat deflection temperature (HDT) and glass transition temperature ( $T_g$ ) to gauge the maximum service temperature for plastics. HDT, which measures the change in stiffness of a plastic as temperature increases, is typically higher for glass-reinforced and other stiffer materials.  $T_g$  is the temperature at which the properties of the plastic undergo a transition from solid state to a viscous liquid. Above this temperature, polymers

lose physical properties rapidly and their dimensional stability becomes marginal. For high temperature applications, a material ideally should have a high value of HDT and no glass transition whatever.

**Table 4** shows the values of HDT and  $T_g$  for several engineering plastics and specialty high temperature polymers. SP-21 displays a HDT of 360°C (680°F) and no  $T_g$ .

**Table 4**  
Glass Transition Temperatures ( $T_g$ ) and Heat Deflection Temperature (HDT) of Selected Materials

Material	HDT, °C (°F) at 264 psi (1.8 MPa)	$T_g$ , °C (°F)
Vespel® SP-21	360 (680)	None
Polyetherether ketone (PEEK), 30% glass	316 (600)	160 (320)
Liquid crystal polymer (LCP)	300 (572)	121 (250)
High temperature nylon, 30% glass	261 (502)	125 (257)
Polyphenylene sulfide (PPS), 40% glass	260 (500)	90 (194)

In summary, Vespel® parts offer a unique combination of high temperature properties:

- No melting point
- 50% property retention for 1,000 hr at 316°C (600°F)
- 50% property retention for 10 hr at 449°C (840°F)
- HDT of 360°C (680°F)
- No  $T_g$

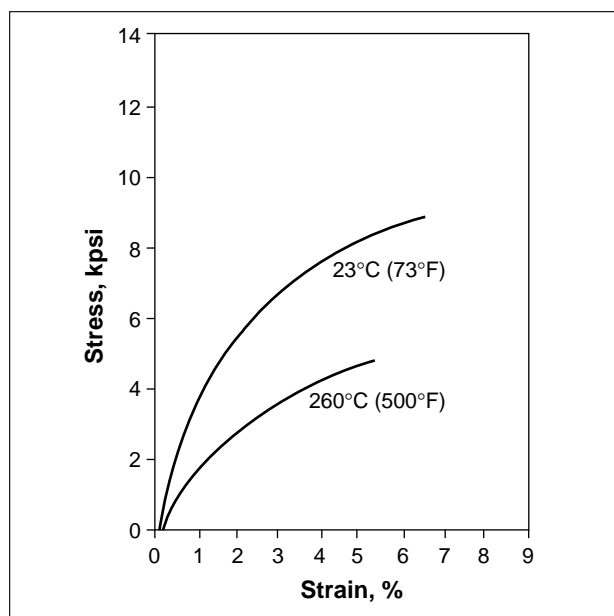
### Sealing Properties

Automotive designers working with dynamic metal-to-metal sealing and valve applications are concerned with a number of factors, including:

- Abrasion and wear resistance
- Permanent deformation of sealing parts
- Seal interference by particulate contaminants
- Surface finish

SP-21 resins show a linear stress-strain curve up to 2% strain (**Figure 5**). This means that seals can recover elastically from 2% deformation. This property allows Vespel® parts to conform to uneven surfaces, eliminating costly honing operations in metal-to-metal seals. Particulates that find their way

**Figure 5. Typical Stress-Strain in Tension for Vespel® SP-21**



between sealing surfaces simply become embedded in the polymer and do not interfere with sealing characteristics.

Various commercial applications demonstrate the superior sealing performance. A disc used in a poppet-type discharge valve of a refrigeration compressor is estimated to have a lifetime of 15 yr running at 1,750 cycles per minute. In another application, a stem guide extends the service temperature and reliability of pneumatic controls. The part remains self-lubricating at 260°C (500°F), does not soften, and withstands repeated impact without deformation.

### Vespel® and Cast Iron Rotary Seal Rings—A Case Study

#### Statement of the Problem

Automotive seal rings require a combination of characteristics that challenges the performance capacity of many engineering materials. These include:

- The ability to seal fluids under pressure over a range of temperature conditions and in the presence of particulate contamination
- Resistance to wear under conditions of high velocity and pressure
- Maintenance of physical properties at the high surface temperatures frequently generated under friction

Rotary seal rings are used widely to maintain fluid pressure in hydraulic circuits such as the clutches of automatic transmissions. In this kind of application, cast iron has long been the industry standard material. Assembly of a cast iron ring on the transmission shaft typically requires automated equipment to expand the ring and slide it into a groove on the shaft. In addition, the most widely used design employs a hook joint that must be brought together in a second assembly step. Because cast iron is a relatively brittle material, ring breakage during installation can be a significant problem.

In a typical transmission application, seal rings are designed to anchor to the surrounding bore when pressure is applied. As a result, most wear takes place on the sides of the seal ring rotating against the faces of the shaft groove. The introduction of hard particulates such as metal fragments can interfere with the free rotation of a seal ring against the groove face. Consequently, sealing deteriorates, which may force the ring to rotate against the bore, and rapid failure ensues.

When transmission shaft speeds approach 7,000 rpm, cast iron rings can wear rapidly under conditions of high temperature and lubricant starvation resulting from low lubricant viscosity. In addition, decreased fluid viscosity at higher temperatures increases the leakage of fluid, necessitating higher fluid pressure to activate clutches.

### Advanced Technology Solutions

Vespel® seal rings, used extensively in heavy-duty off-road equipment and military vehicles, resolve many of the assembly problems associated with cast iron simply because of property differences in the two materials. SP-21 rings can undergo large deformations without breaking, simplifying the installation process. The seal rings do not require hooks to maintain their position in the retaining groove.

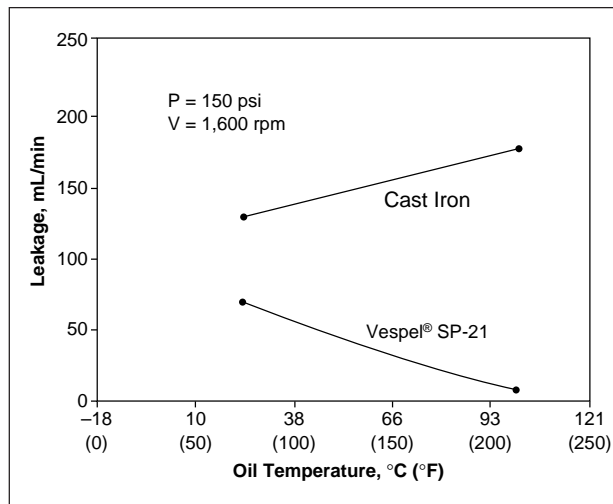
Failure problems resulting from particulate contamination can be eliminated with the polymer rings, which capture metal particles while continuing to seal properly.

Under conditions of lubricant starvation, Vespel® seal rings resist wear much better than cast iron, and they do not undergo catastrophic failure from galling and seizing.

DuPont addresses the seal ring leakage problem by designing rings that take advantage of the materials' thermal expansion. Using available design technology, rotary seal rings can be designed with virtually zero leakage at maximum operating temperature (Figure 6), with a constant rate of leakage at some desired level, or with a leakage profile matching a customer's requirements.

At no additional manufacturing cost, seal rings can be produced with special configurations, such as chamfers and lubrication grooves, that could require extra machining operations in cast iron.

**Figure 6. Sealing Leakage Test: Vespel® SP-21 Seal Ring, 30-mm Diameter Butt-Joint; Cast Iron Seal Ring, 30-mm Diameter Hook Joint**



### Design and Development Support

DuPont works closely with automotive customers in the design, development, and production of seal rings, offering the following services:

- Design of rotary seal rings to meet the customer's functional specifications
- Provision of data validating the leakage performance of seal rings prior to submission of the first prototype
- Full quality certification by recognized criteria
- Parts manufacturing plants in the United States, Europe, and Japan

In summary, these advanced polymer seal rings and other parts can offer a number of benefits over metals in automotive systems:

- Reduced assembly labor and equipment
- Reduced breakage during installation
- Ability to maintain sealing and wear performance in the presence of particulate contamination
- Reduced wear at higher operating speeds and temperatures
- Reduced leakage

Unlike thermoplastics, SP-21 represents more than just a material or a part. It is a complete product service of DuPont, a leading provider to automotive manufacturers and their suppliers worldwide.

### **Application Criteria for Vespel® Parts**

With a long history in the aerospace, automotive, and off-road equipment industries, Vespel® parts and shapes can outperform metals in a variety of challenging applications, including:

- Fuel pump bearings, seals, and valves
- Seal rings, thrust washers, and valves for transmissions
- Bushings and seals for fuel injectors
- EGR valve bearings
- Turbocharger bearings
- Starter bushings and thrust devices
- LPG carburetor seals
- Brake pad wear sensors
- Bearings and thrust devices for small motors
- Piston rings
- Seals, washers, and valves for axles and hydraulic systems
- Suspension and shock absorber components

Consider a new design using advanced polymer parts whenever your applications require:

- Wear resistance at high pressure-velocity ratings, especially when lubricant starvation is a concern or where lubrication is not feasible or desirable
- Operation in surface temperature regimes of 149–260°C (300–500°F) or when high friction may cause conditions of 260–371°C (500–700°F). These materials can even survive short-term exposure to temperatures as high as 427°C (800°F).
- Dynamic sealing against metal parts subject to high PV loading, high temperatures, or particulate contamination.

### **How DuPont Can Help**

DuPont Automotive has been supplying the industry with polymer materials and applications for decades. DuPont has the materials, design expertise, and automotive knowledge to assist you with your development project.

For additional information, contact:

DuPont Automotive  
950 Stephenson Highway  
Troy, MI 48083

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**For more information on  
Engineering Polymers:**

**(302) 999-4592**

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**(800) 533-1313**

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## **U.S.A.**

### **East**

DuPont Engineering Polymers  
Chestnut Run Plaza 713  
P.O. Box 80713  
Wilmington, DE 19880-0713  
(302) 999-4592

### **Midwest**

DuPont Engineering Polymers  
100 Corporate North  
Suite 200  
Bannockburn, IL 60015  
(847) 735-2720

### **West**

DuPont Engineering Polymers  
2030 Main Street, Suite 1200  
Irvine, CA 92714  
(714) 263-6233

### **Automotive**

DuPont Engineering Polymers  
Automotive Products  
950 Stephenson Highway  
Troy, MI 48007-7013  
(313) 583-8000

## **Asia Pacific**

DuPont Asia Pacific Ltd.  
P.O. Box TST 98851  
Tsim Sha Tsui  
Kowloon, Hong Kong  
852-3-734-5345

## **Canada**

DuPont Canada, Inc.  
DuPont Engineering Polymers  
P.O. Box 2200  
Streetsville, Mississauga  
Ontario, Canada L5M 2H3  
(905) 821-5953

## **Europe**

DuPont de Nemours Int'l S.A.  
2, chemin du Pavillon  
P.O. Box 50  
CH-1218 Le Grand-Saconnex  
Geneva, Switzerland  
Tel.: ##41 22 7175111  
Telefax: ##41 22 7175200

## **Japan**

DuPont Kabushiki Kaisha  
Arco Tower  
8-1, Shimomeguro 1-chome  
Meguro-ku, Tokyo 153  
Japan  
(011) 81-3-5434-6100

## **Mexico**

DuPont S.A. de C.V.  
Homero 206  
Col. Chapultepec Morales  
11570 Mexico D.F.  
(011 525) 250-8000

## **South America**

DuPont America do Sul  
Al. Itapecuru, 506  
Alphaville—CEP: 06454-080  
Barueri—Sao Paulo, Brasil  
Tel.: (055-11) 421-8531/8647  
Fax: (055-11) 421-8513  
Telex: (055-11) 71414 PONT BR

DuPont Argentina S.A.  
Avda. Mitre y Calle 5  
(1884) Berazategui-Bs.As.  
Tel.: (541) 319-4484/85/86  
Fax: (541) 319-4417

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