DUPONT™ VESPEL® PARTS AND SHAPES WHITE PAPER

Innovation opportunities in high-heat, low wear and low friction solutions with DuPont™ Vespel®

Abstract

The trend towards space and weight saving in modern engineering applications results in increased thermal and wear resistance expectations of the materials used.
DuPont™ Vespel® products offer unique high performance properties that help overcome severe sealing, wear and friction challenges, endure high temperature and stand up to very harsh operating environments in a wide range of applications. Vespel® parts help keep production running more smoothly, improve throughputs, and raise energy efficiency and system reliability. They enable reduced component size and mass for lighter weight parts, replacing standard metal, ceramics and many other engineering plastics, while broadening the operating window.
This white paper gives product development and design engineers across all industries insights into the unique high performance properties of the Vespel® polyimide material that can become their opportunity for technical innovation.

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1. Industry trends

The need for increased system and process efficiencies and reduced energy consumption drives downsizing by saving space and weight and the search for ever more efficient materials. These are key trends common to engineering design needs for the aerospace, transportation, electronics, and the energy and material handling industries.

Operators, for example, are making major efforts to reduce the energy needed to run processing equipment, while enhancing output. Design engineers want lighter, more compact, low friction components that not only operate at faster speeds, but also last longer – thus raising productivity and reducing cost per unit.

To achieve these goals results in hotter, more confined operating environments with higher fluid pressures, speeds and loads - for which high performance polymers such as DuPont™ Vespel® can offer true innovation opportunities.

2. Vespel® parts and stock shapes

Vespel® polyimide based materials are available as thermosets, thermoplastics, composites or assemblies (Fig. 1) and are positioned at the top of the polymer performance pyramid (Fig. 2) because of their ability to maintain physical and mechanical properties under high loads and temperatures.

The Vespel® material offers a combination of physical properties capable of replacing metals and ceramics, as well as other high performance engineering polymers such as PEEK (polyether ether ketone), and PAI (polyamide-imide). Vespel® parts work long-term in some of the harshest industrial operating environments that cause many other materials to fail. They help keep production running more smoothly, improve throughputs and extend service intervals. Vespel® makes lighter weight parts not only practical, but, in many cases, better than standard metal, ceramics and other engineering plastics.

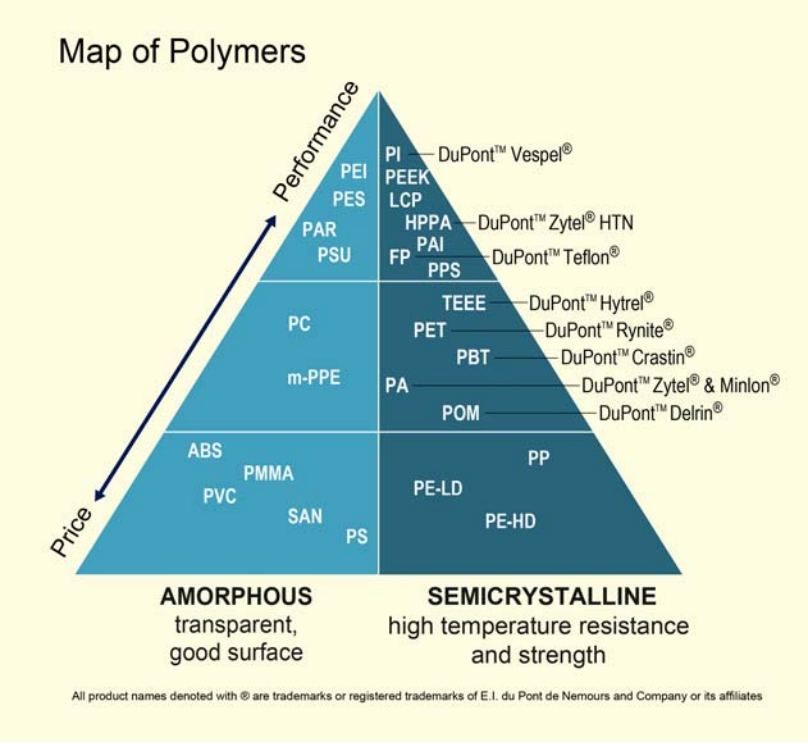

Fig. 1.
Polyimides are positioned at the top of the polymer performance pyramid because of their ability to maintain physical and mechanical properties under high loads and temperatures.

Comparison to metals, ceramics and other plastics

Metals

Vespel® is significantly lighter than metal and has a much lower coefficient of friction, enabling unlubricated operation within a wider operating window, plus high electrical and thermal insulation, unlike metals. Vespel® parts offer opportunities to decrease component or part weight, reduce energy consumption and enable higher engine efficiency.

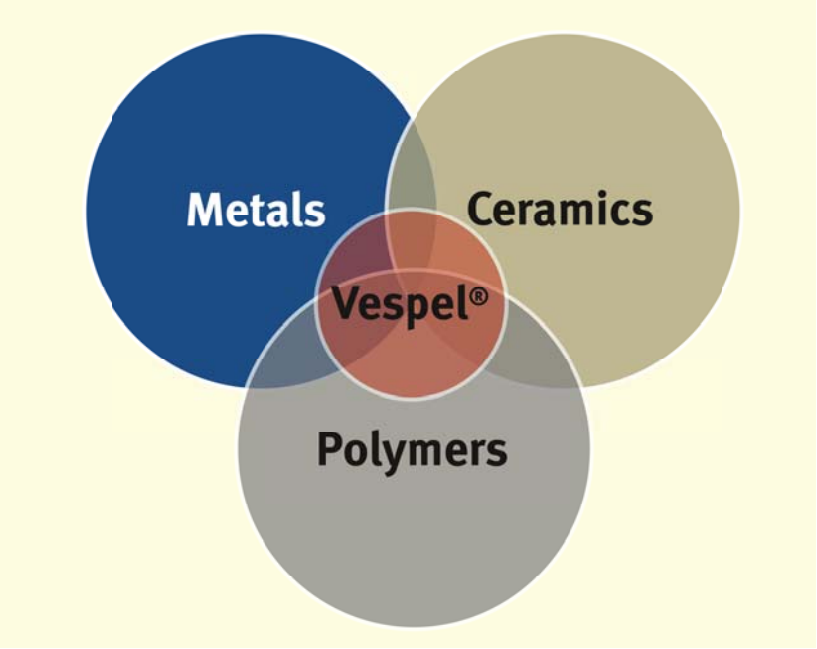

Fig. 2.
Thanks to their unique set of properties, DuPont™ Vespel® parts offer multiple possibilities to replace metals, ceramics, and other high performance polymers.

Ceramics

Vespel® parts are lighter than equivalent ceramic parts, offer better sealing at low pressure, and are easier to machine than brittle ceramics.

Plastics

Vespel® SP grades do not have a melting point and can operate at temperatures from cryogenic (-196°C) to 350°C, with excursions to 480°C and above. Thermoplastic materials, such as PEEK and PAI, can soften or suffer property loss when temperature reaches the glass transition point.

a) Vespel® product families

The complete Vespel® product line consists of five families of materials that provide a unique combination of physical properties, offering great design flexibility. It includes the Vespel® S family of products, the Vespel® CR family with high chemical and creep resistance for applications in the pump, CPI and HPI processing industries; the Vespel® TP family (thermoplastic injection-molded parts from DuPont), the Vespel® ASB family of metal-backed polymer composite and carbon-graphite assemblies, and the Vespel® CP family.

Vespel® S	Vespel® TP	Vespel® ASB	Vespel® CP	Vespel® CR
Direct-formed parts and stock shapes	Thermoplastic injection-molded parts	Assembled parts (metal components)	Composite parts	Chemically-resistant parts and stock shapes

Finished parts and stock shapes

DuPont manufactures **custom finished parts and stock shapes.** For small quantities or complex geometries, DuPont engineers may recommend economically fabricating a finished part from Vespel® S family stock shapes that span a wide range of dimensions and sizes as disks, rings, plaques, bars, rods, tubes and balls. DuPont supplies most Vespel® S and CR grades in the form **of stock shapes via its Authorized Distributors**. Vespel® SMP, TP and CP are not available in the form of stock shapes, but as parts made by DuPont.

For a **list of available stock shapes and sizes,** please see here: http://www.dupont.com/products-and-services/plastics-polymers-resins/parts-shapes/articles/vespel-stock-shapes.html or contact DuPont.

b) Stock Shapes: The Vespel® S family

Vespel® S stock shapes are made from highly durable polyimide resins for demanding applications where exceptional thermal resistance, low wear and low friction, strength and impact resistance are required. The “S” product line includes ”SP” and “SCP” grades:

- **SP family:**
  Vespel® SP grades offer cost-effective combinations of physical, low wear and electrical properties, for lubricated and un-lubricated sealing and low wear in vacuum and dry environments. SP grades have no glass transition (melting point), and are softer than SCP grades, leading to excellent wear characteristics against soft materials like aluminum, and suitability for semi-dynamic applications such as ball valves at high and cryogenic temperatures. SP modulus is almost constant between room temperature and -195°C while most materials become very hard and brittle.

- **SCP family:**
  Vespel® SCP is a DuPont polymer that extends the continual operating performance of polyimide resins to 370°C. SCP grades offer the highest performance of imidized polymers in terms of wear and friction, with high PV limits and low coefficient of friction in unlubricated conditions, compressive strength (similar to carbon steel), and thermal oxidation resistance at very high temperatures.

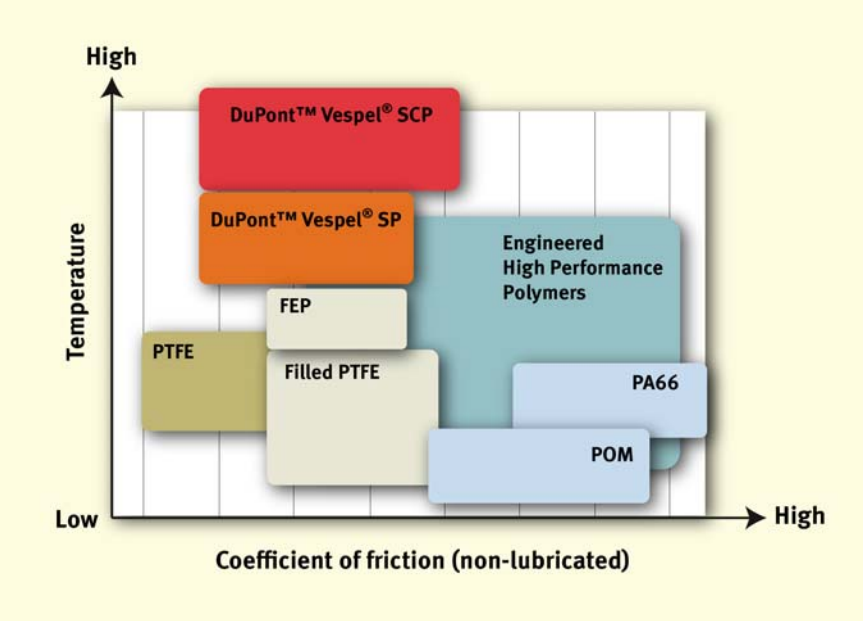

Fig. 3.
Vespel® stock shapes are available in various grades to provide a balance of friction and temperature resistance in demanding applications.

c) Properties overview of Vespel® S

DuPont™ Vespel® parts (whether direct formed or machined) offer properties that help overcome severe sealing, wear or friction challenges, endure high temperature and stand up to very harsh operating environments in aerospace, transportation and industrial applications.

Depending on the grade, Vespel® parts exhibit some or most of the properties listed:

- Cryogenic (-196°C) up to continuous operating temperature at 350°C with short-term use up to 480°C, and up to 650°C for specific products. SP-1 doesn't have a melting point and offers extremely good long-term thermal stability.
- A very low coefficient of friction
- Low wear and low friction at high pressures and velocities (lubricated or unlubricated)
- Outstanding creep resistance
- Good strength and impact resistance
- Lightweight
- Minimal thermal expansion
- High radiation resistance
- High purity, low outgassing in vacuum
- Inherently flame retardant
- Good chemical resistance
- Excellent electrical insulation properties
- Minimal thermal conductivity
- Excellent machinability
- ISO-9001 and ISO-14001 certified.

3. Temperature resistance

Vespel® SP and SCP parts resist temperatures from cryogenic (-196°C) to 350°C, with excursions to 480°C, going beyond the operating window of PEEK and most engineering polymers. Where extreme temperature resistance is required, SCP grades are designed to operate successfully at elevated temperatures, with excursions as high as 650°C.

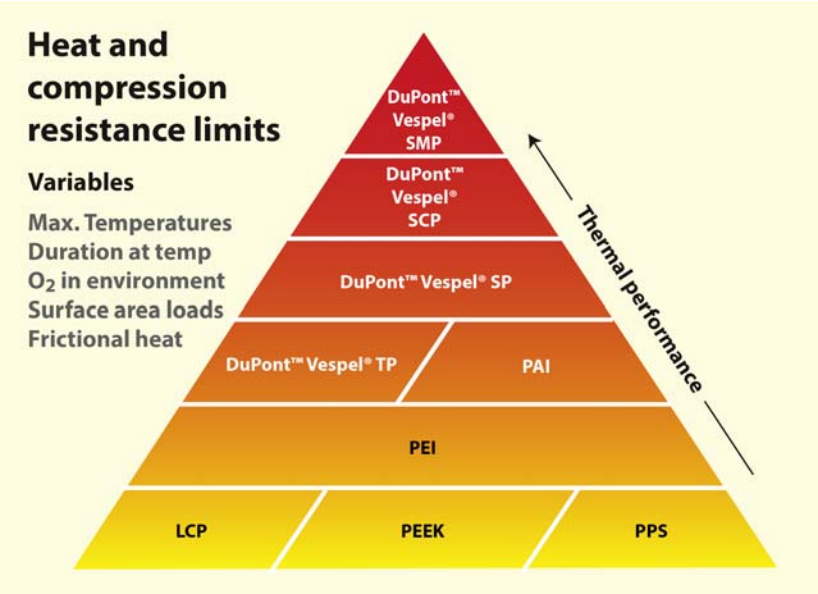

Fig. 4.
Vespel® SCP is one of the best performing products in terms of heat and compression resistance limits.
Source: DuPont

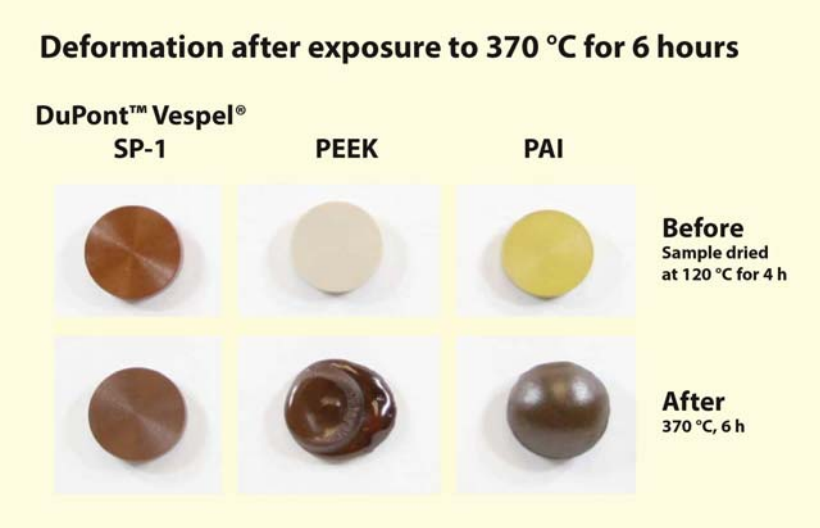

Fig. 5.
The illustration demonstrates the deformation of pure unfilled PEEK and PAI resins after exposure to 370°C for 6 hours, while pure unfilled Vespel® SP-1 remained unchanged. PEEK will soften at 140°C while Vespel® remains essentially unchanged at 350°C+. In addition, Vespel® parts continue to support high loads at this temperature, unlike PEEK.

Source: DuPont

Thermal oxidation resistance

Weight change is an indication of the deterioration of a material following long-term exposure to high temperatures. Figure 6 shows the significant weight loss of a competitive high-temperature engineering plastic after 500 hours exposure to 350°C, while both Vespel® SCP-5000 and Vespel® SP-1 exhibited minimal weight change.

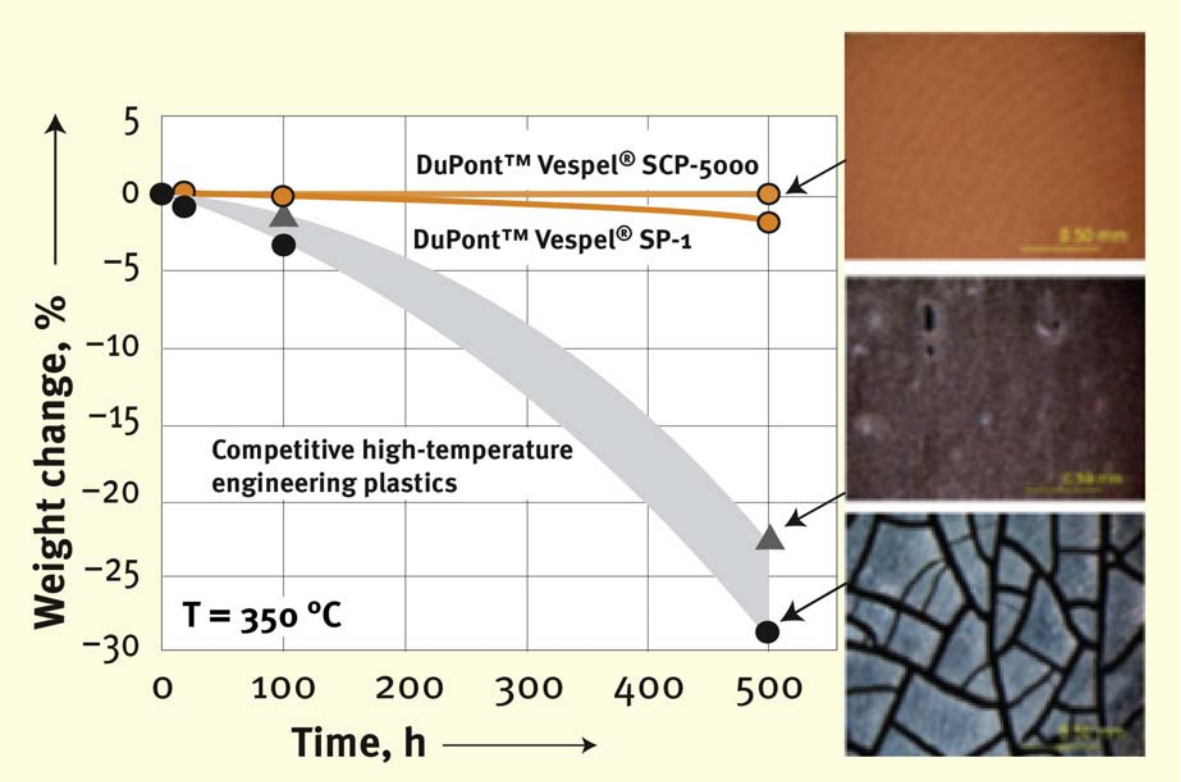

Fig. 6. Weight change: All samples were solid cylinders 10 mm diameter by 20 mm long. All samples dried at 120°C for 4 hours prior to test. Source: DuPont

4. Tribology

a) Definition

Tribology, a branch of mechanical engineering and materials science, is the study of friction, wear and lubrication of interacting surfaces in relative motion.

b) Wear resistance

Friction between moving parts causes wear. Vespel® parts and shapes possess a very low coefficient of friction and resist wear to an exceptional degree. Graphite filled grades are self-lubricating and can operate in dry running conditions. Comparative tests for dry wear behavior of PEEK, PAI, PTFE with bronze, and Vespel® SP-21 and SCP-50094 showed that Vespel® SCP-50094 maintained over 80% (limit of acceptable wear) of the original component material after 5386 hours, and Vespel® SP-21 at 2737 hours, while PEEK, PAI and PTFE with bronze reached the limits of acceptable wear after only 788, 717 and 110 hours respectively.

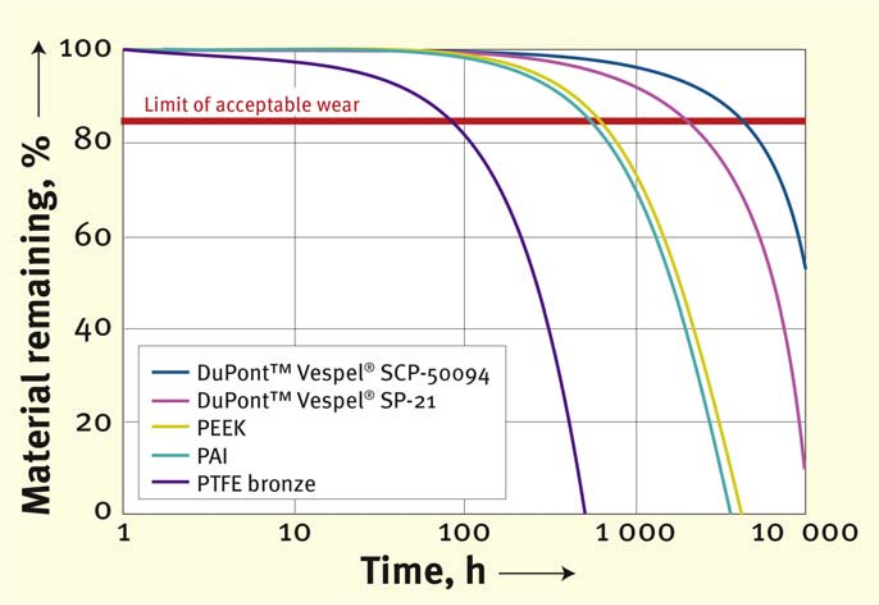

Fig. 7.
DuPont dry wear behavior test of PEEK, PAI, PTFE w/bronze, Vespel® SP-21 and Vespel® SCP-50094 indicates the percentage of material remaining under pressure of 14MPa.m/s (0.7m/s) at 60°C in dry friction running conditions against a PH 17-4 steel Ra 0.4 disk for up to 10000 hours.
Source: DuPont

c) Friction

Design and product development engineers seek to lower energy consumption by reducing friction between moving parts, particularly in the automotive industry, but also for components used in small engines. As transmissions get smaller, lighter and spin faster, engineers are pushing the limits of the wear, friction and temperature capabilities of existing materials.

Vespel® S resins have an exceptionally low coefficient of friction coupled with high load and wear resistance. This enables higher shaft speeds and loads, and lower lubrication. Vespel® parts can replace metal bearings, thus reducing overall size and weight.

DuPont test results (Fig. 8) show up to 40% reduction in friction between Vespel® thrust washers and a steel counter surface compared with thrust washers of PEEK and PAI, resulting in minimal wear, lower energy losses and faster running. Vespel® bushings, bearings, valve seats and seals don't present the inefficiencies of metal to metal contact, particularly in run dry situations. Vespel® parts can better conform to metal parts resulting in better mating and sealing, even in low to non-lubricated conditions. Due to their excellent wear resistance against aluminum, for example, these parts may eliminate the need for heavier steel inserts or sleeves. They also offer better friction resistance than PEEK at elevated temperatures.

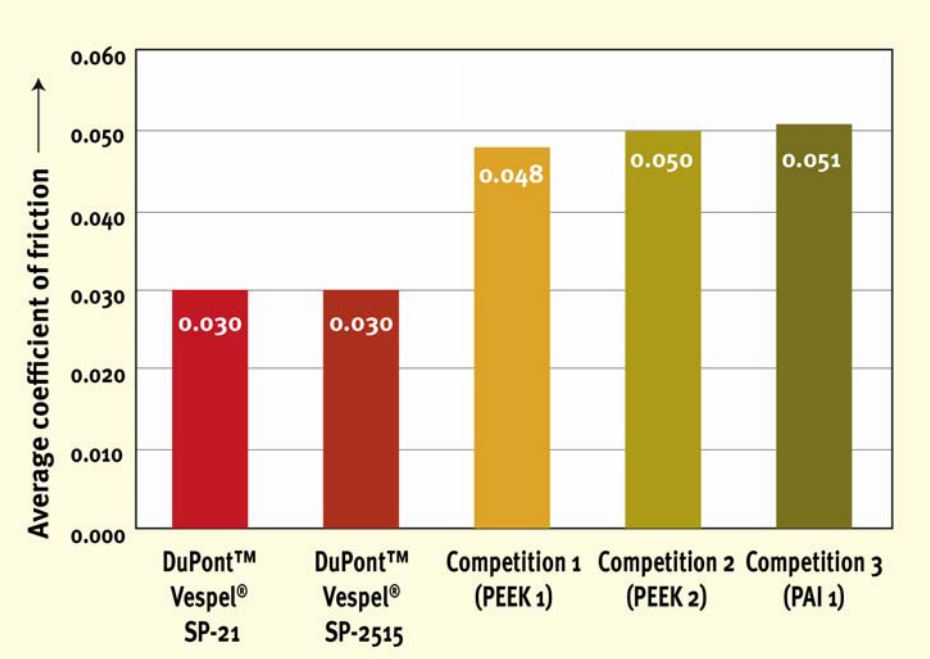

Fig. 8.
Example of coefficient of friction benchmark data comparison measured under lubricated conditions. Up to 40% reduction of coefficient of friction measured for Vespel® SP DF2. #

Test conditions: Lubricated CoF in Automatic Transmission Fluid against Steel 42CrMo4, HRc 50, Ra 0.3 um, 23 MPa.m/s. Source and test method: DuPont

d) Pressure velocity (PV) resistance

Vespel® has greater resistance to contact pressure and velocity (PV), high loads and temperatures than either PEEK or PAI. Highly PV resistant Vespel® parts enable design engineers to increase unlubricated running speeds or loads by up to 50% in dynamic applications, reduce part size, and even eliminate the need for pressurized lubricating systems, reducing cost and complexity.

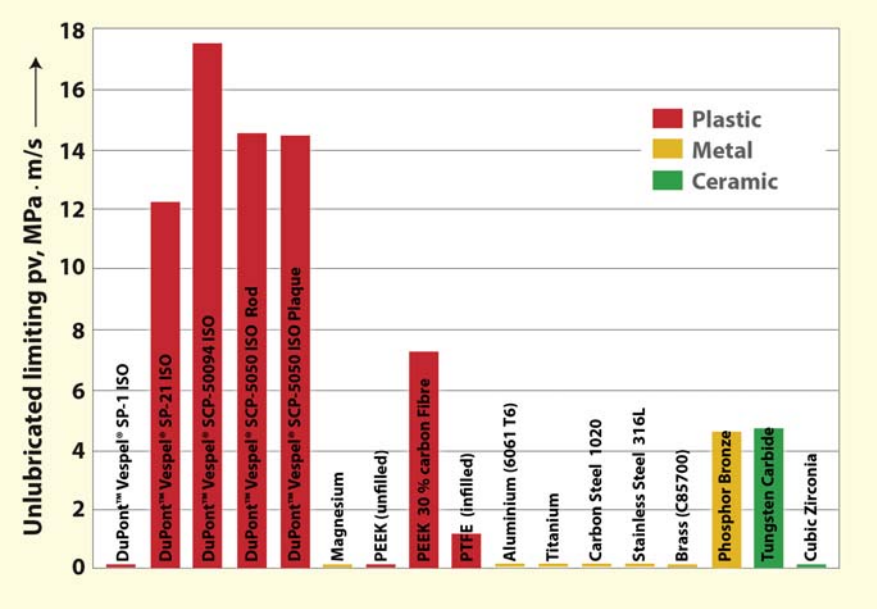

Fig. 9.
The chart illustrates the maximum unlubricated operating PV limits of plastics, metals and ceramics. Vespel® SCP-50094 ISO offers excellent PV resistance and compressive strength above 17 MPa.m/s, closely followed by Vespel® SCP-5050 ISO and SP-21 ISO. The worst ratings are exhibited by materials that perform poorly in unlubricated PV environments such as magnesium, unfilled PEEK and PTFE, aluminum, stainless steel and cubic zirconia. Source: DuPont

5. Other product characteristics

a) Weight aspects

Vespel® S products have densities ranging from 1.43 to 1.77 depending on grade. At same loads, parts can be designed lighter and smaller than equivalent metal and ceramic parts. Conversely, Vespel® parts of the same size and geometry can withstand higher loads and temperatures than the parts they replace.

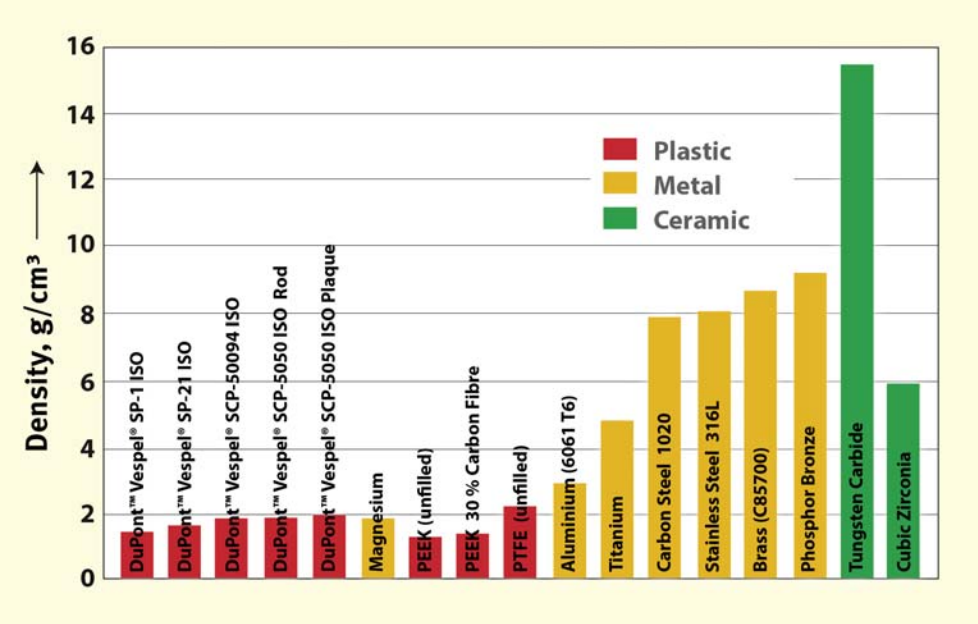

Fig. 10. The above chart compares the densities of commonly used engineering materials, and highlights the low density and light weight of Vespel® grades versus most metals and ceramics.
Source: DuPont

b) Isostatic stock shapes and machined parts

Many Vespel® S stock shapes are an isostatic material, i.e. their mechanical and physical properties and dimensional stability remain consistent in any direction, also after machining. Direct formed (DF) parts feature some directional properties.

c) Flame/electrical resistance

Vespel® SP-1, SP-21, SP-211, SP-22 meet the requirements of the Underwriters Laboratories UL94 5V or 94V-0 flammability ratings for the safety of flammability of plastic materials for parts in electrical equipment and accessories

Vespel® SP-1 and SCP-5000 are unfilled polymers that combine high dielectric strength, low dielectric constant, thermal oxidation and ion degradation resistance. They are used to make tough electrical thermal insulators for scientific instrumentation, analytical equipment, avionics, communications, ultrasonics and transformers, that perform under impact loads where ceramics fail.

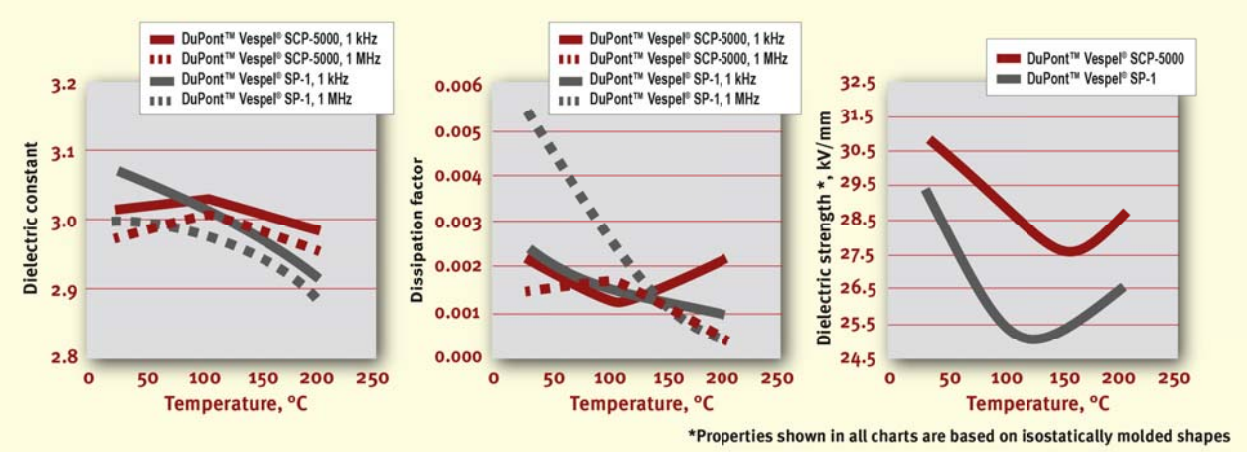

Fig. 11. Vespel® SP-1 and SCP-5000 present excellent dielectric properties, making these materials ideal for electrical and thermal insulation applications. Source: DuPont

c) Easy machining

Vespel® shapes are easy to machine with standard metalworking equipment, and are also suitable for carbide tooling. You can use just about all machining processes on Vespel®: turning, drilling, milling, sawing, grinding, polishing, and lapping, including laser drilling, laser etching, selective etching, and laser marking. The TP family of grades can also be transformed using energy type processes like ultrasonic welding.

Compared to most other high performance plastics, Vespel® shapes generally do not require post processing or annealing, and are very stiff and non-brittle to work. They are minimally affected by water, and can be machined to very close tolerances. Ask for our machining guide.

6. Uses and application

Vespel® has been used in a wide variety of applications and parts since 1965. For example, you can find Vespel® parts in aerospace, automotive, farm equipment, in semiconductor processing, snowmobiles, and in many more applications.

Energy and material handling, mechanical engineering, small engines, industrial applications, machinery, glass handling, pumps, compressors

Bearings, bushings, wear rings and insulators are widely specified for applications requiring outstanding thermal, mechanical and chemical properties. They are also used to make electrical thermal insulators for scientific instrumentation, analytical equipment, avionics, communications, ultrasonics and transformers, to perform under impact loads where ceramics fail.

Transportation
Transmission wear rings, bushings and thrust washers are used where low wear, low friction, and resistance to high loads and aggressive fluids are key requirements.

Aerospace
Vespel® bushings, washers, wear pads, wear strips and tube clamps are specified for low wear, low friction and lightweighting applications in aero engines.

Electronics
Vespel® test sockets and wafer guides are chosen for their excellent electrical and mechanical properties, plasma resistance, low outgassing and high oxidative stability in electronic testing and wafer handling applications.

7. Consider using Vespel® for your application

DuPont™ Vespel® parts deliver unique properties by combining continuous operation at cryogenic to high temperatures, low wear and low friction at high PV in lubricated or unlubricated environments, plus outstanding creep, strength and impact resistance, exceptional dimensional stability, low thermal expansion and easy machinability.

Consider using Vespel® material:

1. for critical applications such as **aerospace or military** where DuPont™ Vespel® may be the **ASTM specified product**.

2. for **high temperature environments** with no loss of properties.

3. for **high load** applications such as bearings.

4. as a long-lasting material with **low friction and high stability combined with heat and wear resistance**.

5. for **weight savings:** DuPont™ Vespel® can be an excellent alternative to metals such as aluminum or metallic alloys, or ceramics. Its properties may even exceed that of metal and ceramic.

6. when lubrication may not be viable, when you need a low wearing material that can withstand poor tolerances or when you need **low friction** to improve efficiency. **Vespel® SCP-50094 possesses some of the highest unlubricated pressure-velocity** limits among engineering plastics.

7. as an **easy to machine** alternative to ceramic. DuPont™ Vespel® has **electrical insulation** properties like ceramic, but its ease of machining using standard machining techniques means it can cost less to fabricate Vespel® than ceramic. This is especially true for designs that include details like under cuts, holes, or threads. Vespel® is also tougher than ceramic and it can take high impact.

8. in a critical testing environment or when you need a **low outgassing** product.

9. when you need good chemical resistance or a material that will work well under hard vacuum, radiation, oxygen compatibility, cryogenic conditions, and exposure to flame.

Vespel® parts and stock shapes provide trusted solutions to many challenging applications that apply temperature extremes, high friction, excessive wear and heavy loads to critical moving parts.

We can help you determine if Vespel® could be the right material to help improve your current application, and open up opportunities for innovation in new applications.

Visit us at **kalrez.dupont.com** or **vespel.dupont.com**

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