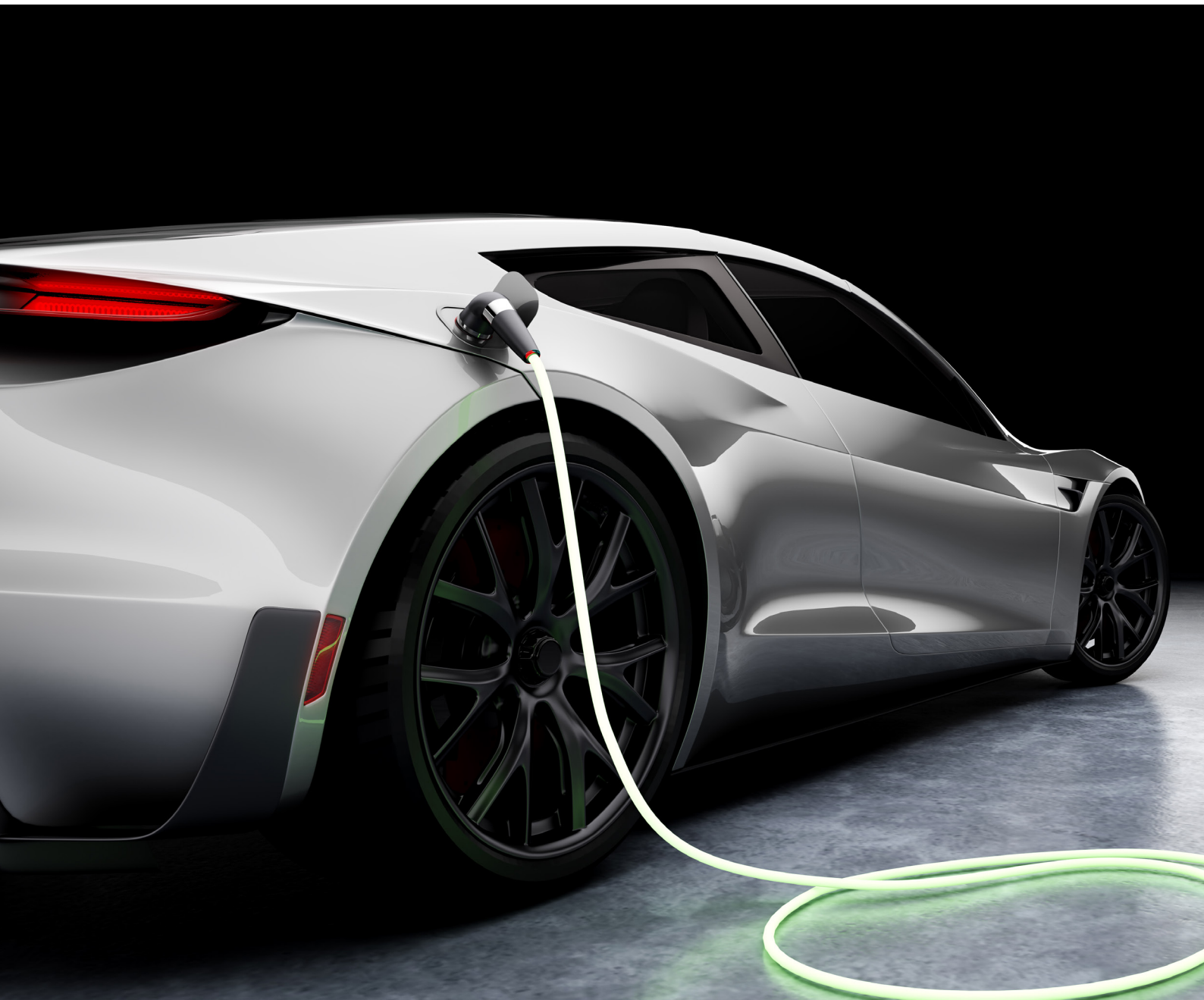


DuPont™ Vespel® Parts for Automotive Applications (xEV & ICE)



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Introduction

The automotive industry has undergone significant advancements and transformations since the advent of the internal combustion engine (ICE) during the 1870s. This pursuit has been to achieve more efficient and cost-effective transportation of goods and people across land. Over the past century, the industry has witnessed innovations in powertrain components, such as engines and transmissions, to meet consumer and regulatory demands for increased fuel economy and horsepower. As a result, the materials used in these components had to be lightweight, durable, and capable of withstanding high thermal and mechanical loads, while enabling the manufacturing of complex 3D geometries. As the automotive industry shifts toward electrification to mitigate carbon emissions, there will be a greater demand for innovative materials. This demand will continue to grow as automakers develop novel solutions in electric propulsion and battery applications.

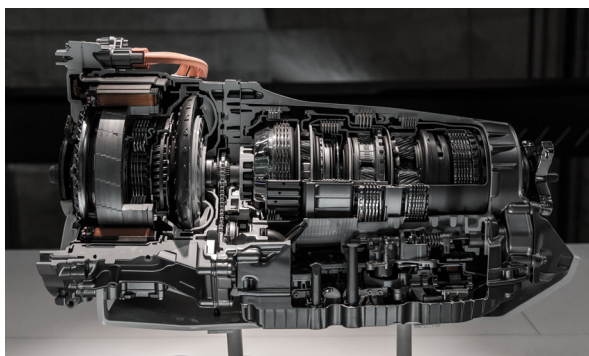
When comparing xEV¹ with ICE, familiar material challenges exist: minimizing wear & friction and durability under high temperature, torque, and speed. New challenges such as electrical insulation and hydrogen permeation will also need to be addressed.

1 – xEV denotes all variants of electric vehicles, including Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV), Hybrid Electric Vehicle (HEV), and Fuel Cell Electric Vehicle (FCEV)

DuPont™ Vespel® Polyimide Parts

DuPont™ Vespel® is the brand name for a range of high performance, mainly polyimide-based plastics. Vespel® SP polyimide was originally developed in cooperation with NASA for the Apollo Space Project.

Over the past 50 years, the Vespel® parts and shapes portfolio has expanded to include a variety of different grades, each with unique performance characteristics accomplished by varying the types and levels of fillers and different manufacturing methods for parts or shapes. Vespel® parts and shapes are excellent tribomaterials with exceptional thermal resistance, low wear and/or low friction properties. They are ideal for demanding applications in transportation in both dry and lubricated environments.



**Your partner of choice for
innovative automotive
development**

Typical Vespel® Parts



Thrust Washer



Bushings



Seal Rings



Thrust Plugs



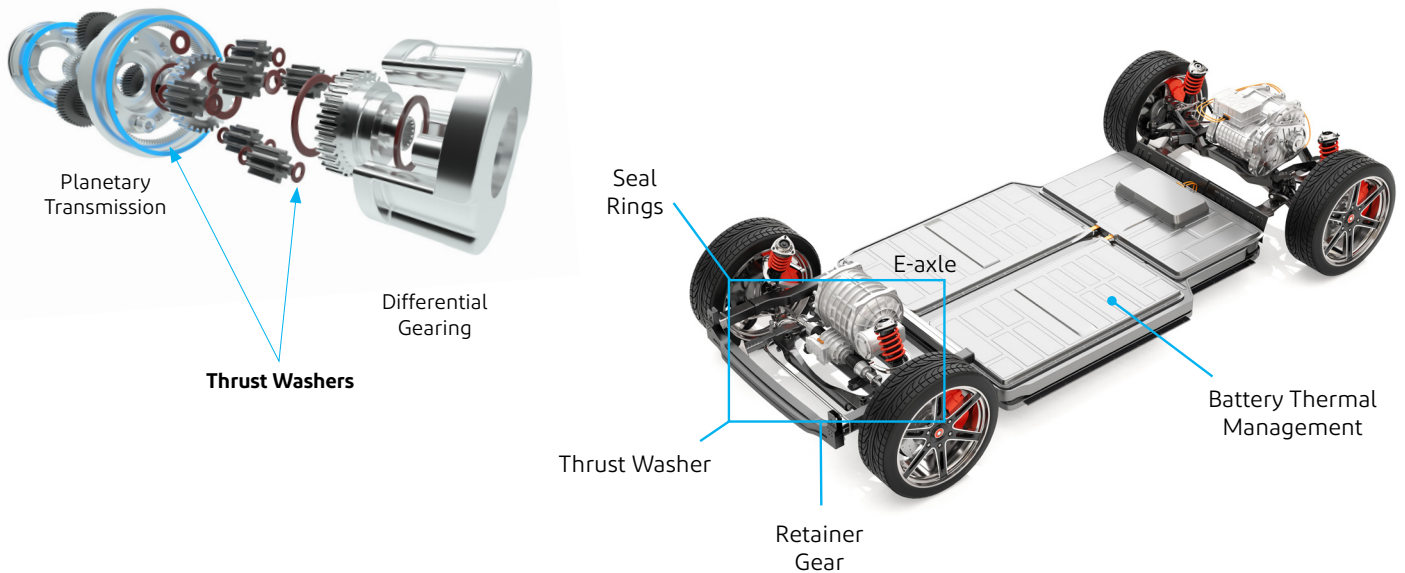
Ballbearing Cages



Insulation

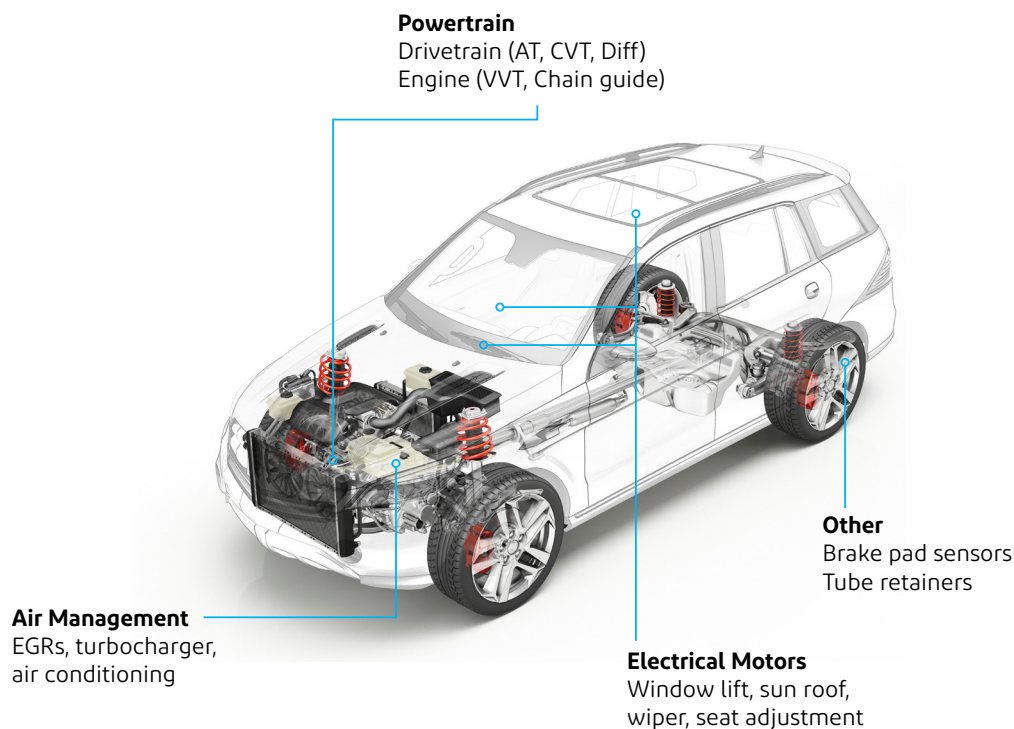
Typical Applications in xEV Vehicles

As the industry moves toward electrification, so does Vespel®. Our materials are best suited for high Pressure-Velocity (PV) applications in e-axle for reliable electric propulsion. Vespel®'s excellent electrically insulative properties also make it suitable for battery applications.



Main Application Areas in ICE Vehicles

Vespel® materials have been used in automotive vehicles for more than 50 years, ranging from powertrain applications in transmission planetary gear sets and wastegate in turbochargers to auxiliary components in electrical motors, where frictional wear needs to be mitigated.



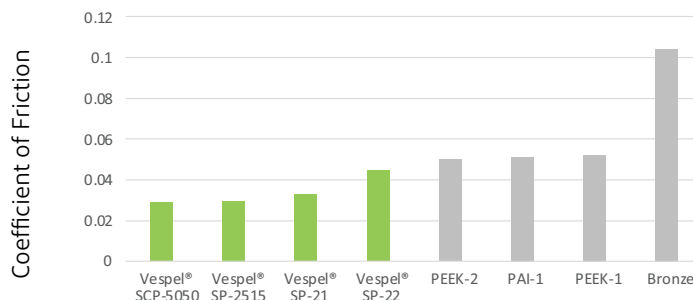
Key Properties of Vespel® for Automotive Applications

Wear and Friction – Dry and Lubricated

Automotive gearboxes and transmissions require lubrication to operate as the motion of metallic gears generate frictional heating. In other applications, such as wastegate, an unlubricated environment is expected. Materials for all these applications must endure stringent Coefficient of Friction (CoF) and Pressure-Velocity (PV) requirements for low wear rates and prolonged lifespan.

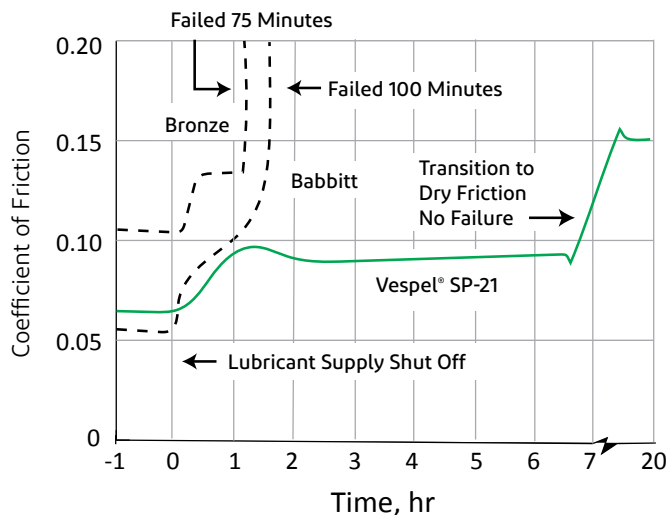
Vespel® parts are used as thrust washers to separate metallic parts while enabling the transfer of energy down the powertrain. Compared to other engineered plastics, Vespel® exhibits lower coefficient of friction to maximize power transfer efficiency (Figure 1).

Figure 1: Friction Properties Under Lubricated Conditions



In the event of a lubrication starvation scenario, the fillers in select Vespel® grades, such as Vespel® SP-21, provide the dry lubrication properties to maintain a low coefficient of friction while preventing machine failure, whereas unlubricated metals will failure within hours of dry operation (Figure 2).

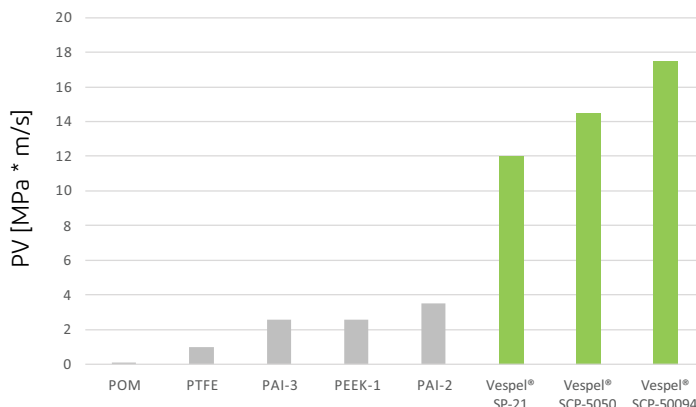
Figure 2: Emergency Operating Features of Vespel®



Carbon Steel, Pressure = 500 psi (3.5 MPa), Velocity = 20 ft/min (0.1 m/s)

In a test to characterize unlubricated PV (Pressure-Velocity) limit, Vespel® SP-21 achieved 3x higher limit compared to the competition. High performance grades, such as Vespel® SCP-50094, reached beyond 4x (Figure 3).

Figure 3: Unlubricated Limiting PV (MPa-m/s)

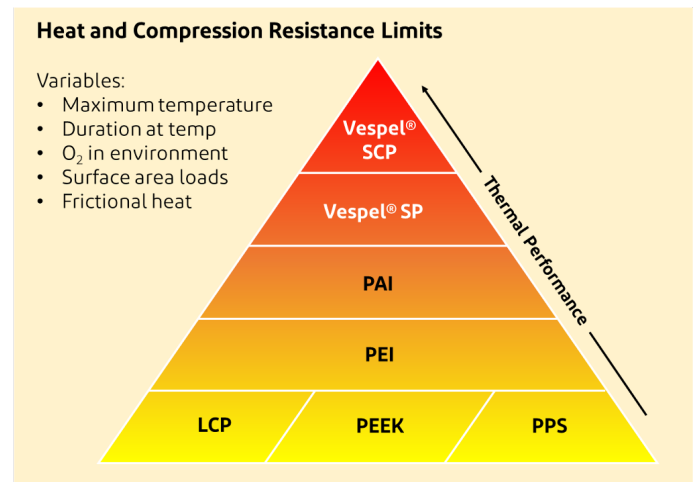


Key Properties of Vespetel® for Automotive Applications, continued

High Temperature Durability & Resistance

High temperature resistance is a key property especially with automotive ICE powertrain applications. For example, a well lubricated engine can reach 90 °C - 105 °C. However, a turbocharger wastegate in a non-lubricated state can reach in excess of 300 °C.

A unique feature of Vespetel® SP and SCP polyimide is the high temperature resistance at 288 °C and withstands excursions beyond 350 °C. The highly crosslinked nature of the polyimide backbone enables Vespetel® to have superior thermal performance compared to other engineered plastics such as PAI, PEI, and PEEK. Vespetel® polyimide does not melt and can withstand harsh conditions longer than competitive plastic or metallic solutions.



In a side-by-side comparison of Vespetel® SP-1 and SCP-5000 versus PAI and PEEK at 370 °C for 50 minutes, the competitive materials have deformed severely while the Vespetel® parts maintained the original shape without noticeable effects.

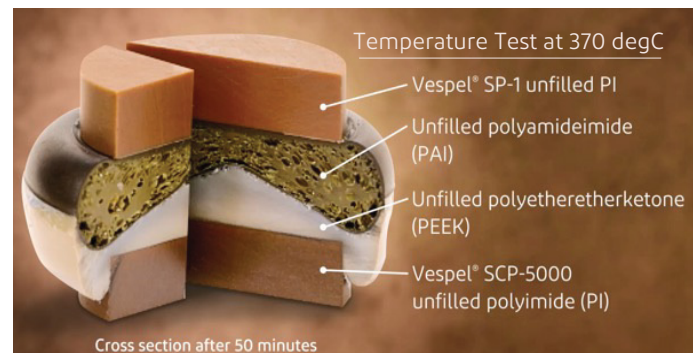
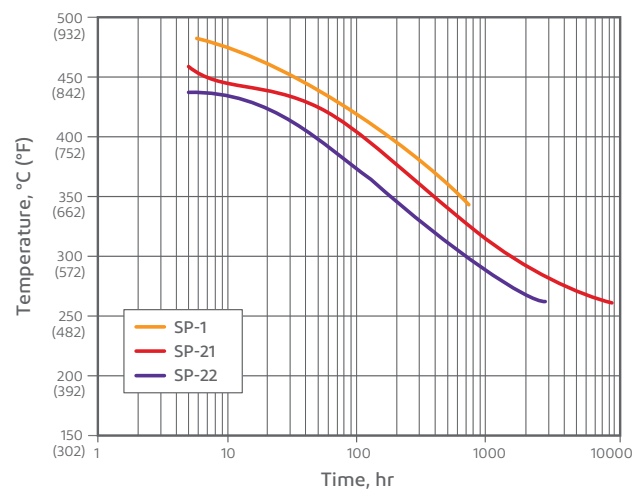


Figure 4: SP polyimide exposure to air at elevated temperature. Approximate time to 50% reduction in tensile strength vs. temperature



The durability of Vespetel® parts at continuous elevated temperature enables long hours of service before reaching 50% of the original tensile strength. For SP-1 at 300 °C, this meant 1000+ hours (Figure 4).

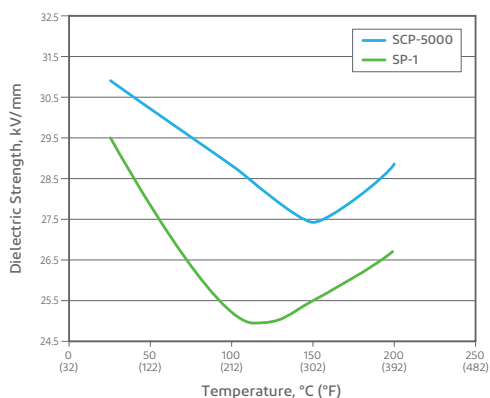
Compelling Properties of Vespel® for xEV Applications

Electrically Insulative Properties

High voltage battery and propulsion systems require electrically insulative materials to prevent pre-mature failure due to short circuiting with neighboring electrified components.

Vespel® SP-1 exhibits excellent dielectric properties compared to other polymers, such as PEEK. Additionally, the high temperature durability of Vespel® enable only a minimal drop in dielectric strength from room temperature to 200 °C (Figure 5).

Figure 5: Influence of temperature on Vespel® polyimide dielectric strength



Material	Dielectric Strength (kV/mm)	Volume Resistivity (ohm-cm)	Surface Resistivity (ohm/sq)
Vespel® SP-1	29.5	5.5x10 ¹⁶	4.0x10 ¹⁶
PEEK	19	5.0x10 ¹⁶	1.0x10 ¹⁶

Reference: PEEK data from Brydson's Plastics Materials (8th Edition)

Hydrogen Permeation and Creep Resistance

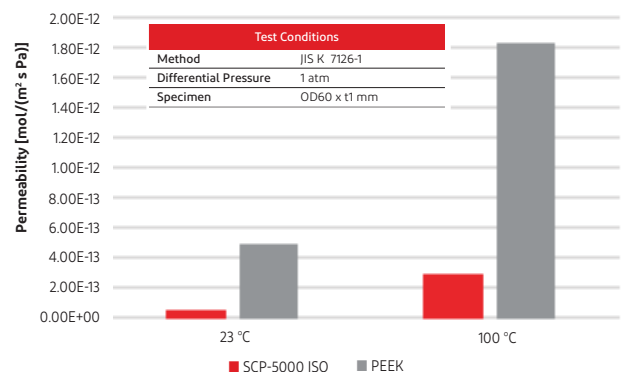
FCEV are gaining traction alongside BEV and PHEV. Additionally, ICE powered by hydrogen are being developed by strategic players in the industry. Challenges in the hydrogen storage and transport inside the vehicle need to be addressed.

Hydrogen permeability is a key material property to understand regarding the containment of the fluid over a long period of time. The lower the permeability, the better the material's ability to contain hydrogen and avoid leakage. When compared to PEEK in similar conditions, Vespel® polyimide parts show significantly lower hydrogen permeability, which even remains reasonably low when tested at higher temperatures (Figure 6).

Hydrogen leaks largely originate from deformed seals or gaskets. Therefore, materials used in sealing elements should display excellent creep performance. Vespel® polyimide exhibits lower % deformation change compared to PEEK (Figure 7).

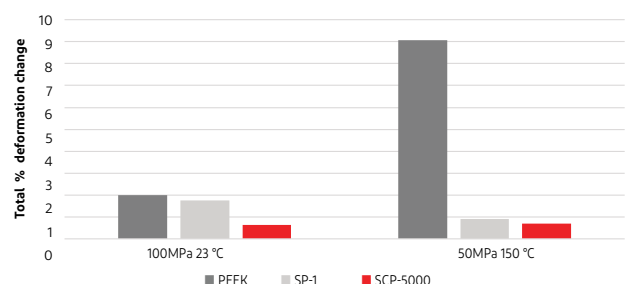
Vespel® exhibits high dimensional stability, while maintaining its sealing performance over a long service lifetime. Other important properties related to hydrogen environment are covered in the DuPont™ Vespel® Parts for Hydrogen Energy brochure.

Figure 6: Hydrogen permeability



Hydrogen permeation tests were performed via gas chromatography using a differential pressure method.

Figure 7: Creep performance in compression after 600 hours



Test specimen: Ø8 mm x h16

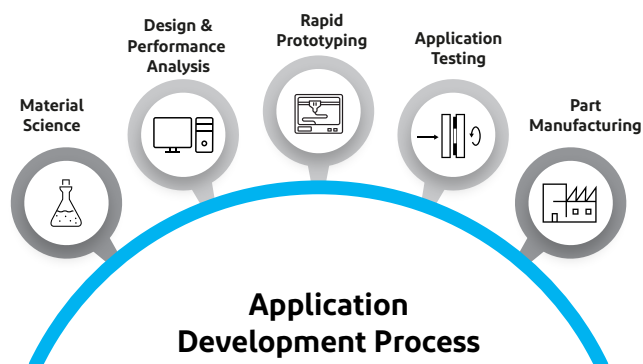
Application Development Process

The DuPont Vespel® team works closely with the customer from the beginning stage of project conception to final implementation. A crucial component in this journey is the Application Development process to support the customer's evaluation and refinement of the Vespel® parts.

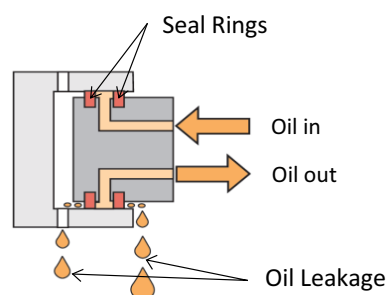
There are five steps to the Application Development Process:

1. Material Science – Selection from a portfolio of Vespel® grades for a wide range of applications
2. Design and Performance Analysis – In-depth knowledge of the Vespel® grades and performance they provide
3. Rapid Prototyping – Sampling of physical parts for customer testing and evaluation
4. Application Testing – Custom test rigs developed and supported by our Centers of Excellence
5. Part Manufacturing – Finalize commercial part geometry and tolerances to meet customer needs

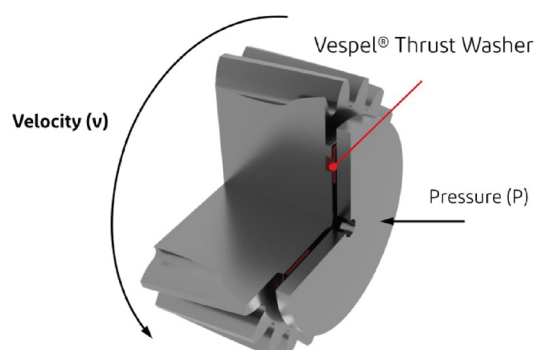
In our Tribological Lab, we have customized test rigs to evaluate the wear and friction performance in dry- and oil-lubricated environments. We also have a team of tribologists to help support Application Development.



Schematic of a seal ring testing apparatus to check for the oil leakage



3D model of the thrust washer test rig with an axial pressure load and a rotational velocity applied



Summary - Vespel materials enable success

Vespel® is the answer to the most stringent wear and friction and high temperature requirements in automotive applications, thanks to its unique blend of thermal, mechanical, and tribological properties.

Challenges in automotive applications



Higher torque and speed with demand in instant acceleration = high PV



Low CoF with high PV limit. Minimizing wear and reducing friction while preventing seizure/fretting of rotational components.



High temperature due to frictional heating in powertrain



Higher long term temperature resistance compared to PEEK and PAI



Potential lean lubricating conditions



Self lubricating, does not melt, operates under lean lubricating levels with optimized oil groove design



Demanding electrical requirements for high voltage systems



Excellent dielectric properties from room to elevated temperatures



Hydrogen leakage through permeation and/or loss of dimensional stability of sealing material under cryogenic high-pressure environment



Excellent creep resistance combined with significantly **lower hydrogen permeability** compared to materials such as PEEK

Vespel® Selection Guide by Application

Typical Applications	Component	SP-1 Maximum strength and elongation	SP-21 Enhanced wear resistance	SP-22 Maximum creep resistance	SP-2515 Match aluminum's CTE	SCP-5050 Lowest CTE	SCP-50094 Highest PV limit
Transmissions (xEV & ICE) Variable valve timing Hydraulic motor	Seal Ring 		X	X	X		
Transmissions (xEV & ICE) Differential unit Lubricated clutch system	Thrust Washer 		X		X		X
Emission systems (EGR, Turbocharger) Solenoid valves	Bushing 			X	X	X	
Electrical motors (window lift, wiper, seat, sunroof)	Thrust Plug 	X	X				
Transmissions (xEV & ICE) Variable valve timing	Aluminum wear & friction 		X		X		
Chain guide Shift fork pad	Wear Pad 	X	X				
Hydrogen valve seats	Hydrogen Seal 	X				X	



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