AEROSPACE

DuPont™ Vespel® Parts for Hydrogen Propulsion Technology

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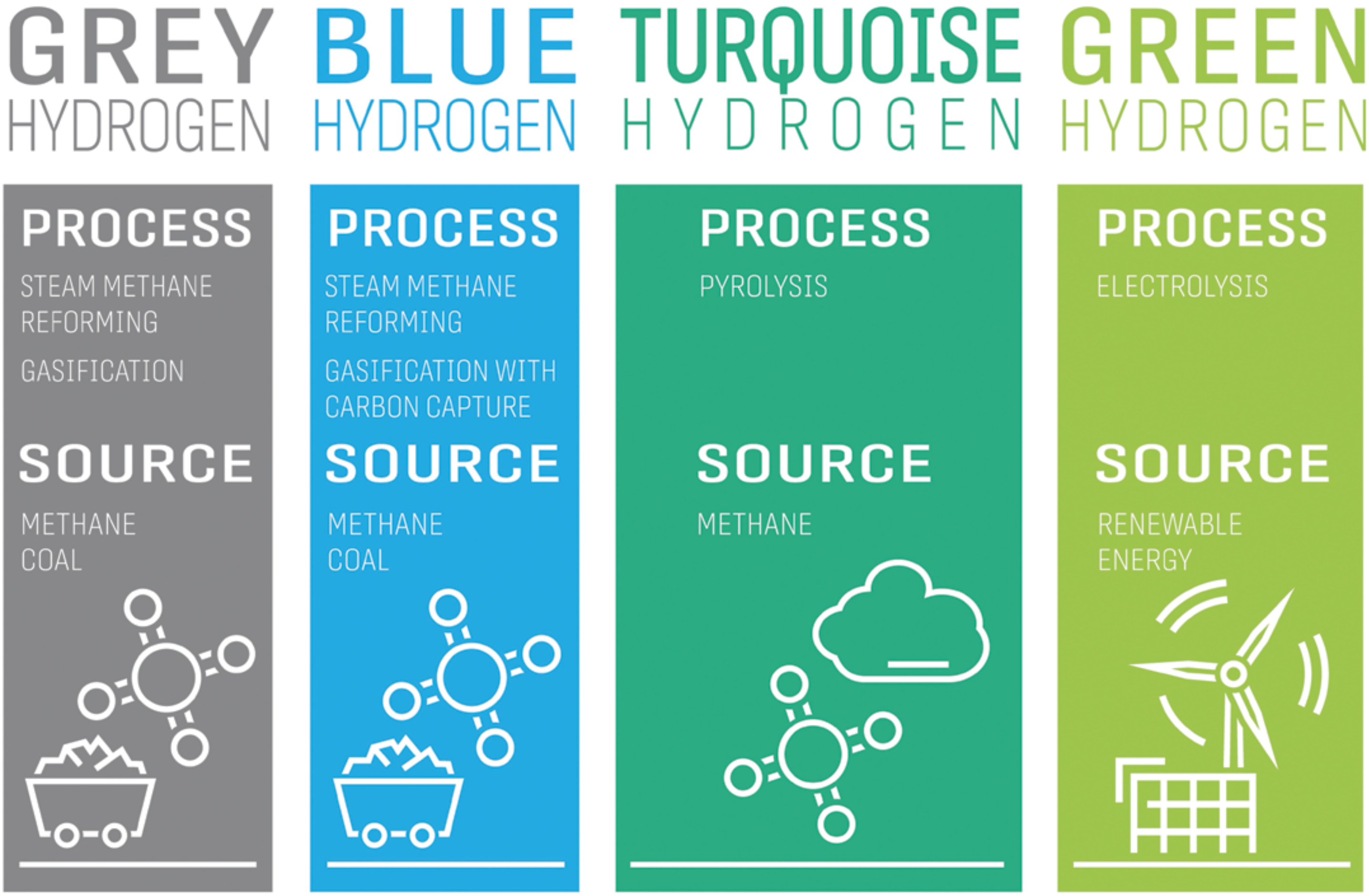
Introduction

Given the current environmental challenges linked to greenhouse gas emissions, hydrogen has the potential to become an important alternative fuel source for aviation. Hydrogen has the advantage of only generating water as a byproduct when combusted for energy, making it well-suited to support zero-emission aircraft. Hydrogen is a high-potential technology with a specific energy-per-unit that is three times higher than traditional jet fuel.

However, large-scale, economical production of hydrogen itself without the generation of greenhouse gasses is still a challenge. The most common method of producing hydrogen, often referred to as grey hydrogen, involves decarbonating methane using steam methane reforming. This process releases CO_2 as a byproduct. To make this process cleaner, technology is being developed to capture the CO_2 generated. With this added step, this type of production is often referred to as blue hydrogen. Alternative processes that eliminate the creation of CO_2 during hydrogen production are also being developed. These processes are referred to as green hydrogen, and generally refer to the production of hydrogen through the electrolysis of water via a renewable energy source. The byproduct of this process is simply oxygen, thus eliminating emissions of any greenhouse gasses.

Types of Hydrogen Production



Challenges of using hydrogen in alternative – propulsion technology

Widespread adaptation of hydrogen as an alternative fuel source brings about a set of requirements different from those of fossil fuels. Designing safe, efficient, and environmentally-friendly processes for the production, conversion, transportation and supply of hydrogen is critical.

Storage and Transportation

Hydrogen's volumetric energy density is extremely low compared to other fuels. Therefore, to be a practical fuel source its energy density must be increased. This is commonly achieved by either compressing hydrogen gas to pressures between 350-700 bar, or by liquifying hydrogen by cooling it to -253 °C at atmospheric pressure. In both of these states hydrogen's volume is reduced to a more reasonable size for storage and transport. However, maintaining hydrogen as a liquid or compressed gas can be difficult. Tanks with proper thermal insulation or active cooling systems are necessary to keep hydrogen in its liquid state for extended periods of time. Furthermore, systems must balance both efficiency and cost effectiveness, a particularly complicated challenge due to the significant temperature variation produced by rapid pressure change during hydrogen transfer and dispensing.

Safety

Hydrogen is highly reactive and can ignite in air at concentrations as low as 4%. Due to this, safety is a concern if uncontrolled hydrogen leakage occurs. Because of its low molecular weight, pressurized hydrogen molecules can permeate certain materials, including metals, leading to cracks. This phenomena, called hydrogen embrittlement, can significantly reduce the ductility of solid metals and is common when metals are in contact with hydrogen at variable high pressures.

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. Vespel parts and shapes are resistant to high and low temperatures, creep, wear, hydrogen embrittlement and a variety of chemicals. Coupled with their insulative properties and low H_2 permeability, they are well-suited solutions for the applications of compressing, transporting, and storing hydrogen.

Key properties of DuPont™ Vespel® for Hydrogen Sealing and Storage

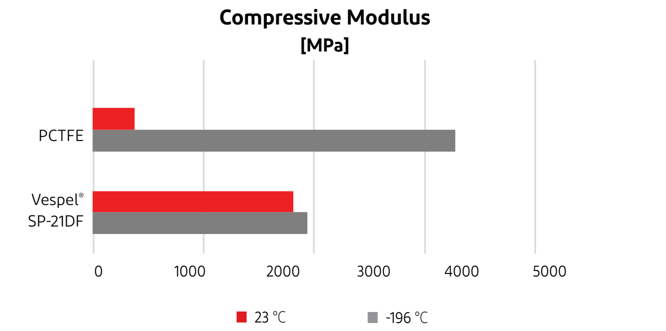
Low and consistent modulus and higher mechanical resistance

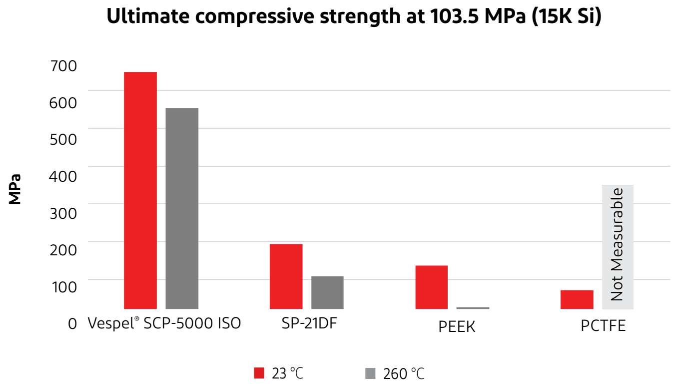
The "soft but strong" behavior of Vespel® is a key advantage in cryogenic and hydrogen valve applications, where it is necessary to maintain sealing performance at low temperatures.

To obtain an excellent seal for hydrogen applications, the seal must perform well in both cryogenic and high temperatures and withstand sudden changes in temperature and pressure while maintaining its mechanical properties.

The elastic modulus of Vespel® is very stable at temperatures ranging from ambient to cryogenic, unlike other polymers such as PEEK and PCTFE, which lose elasticity at lower temperatures.

Additionally, Vespel® parts provide better ultimate compression resistance which surpass both PEEK and PCTFE, with only a slight drop at higher temperatures.

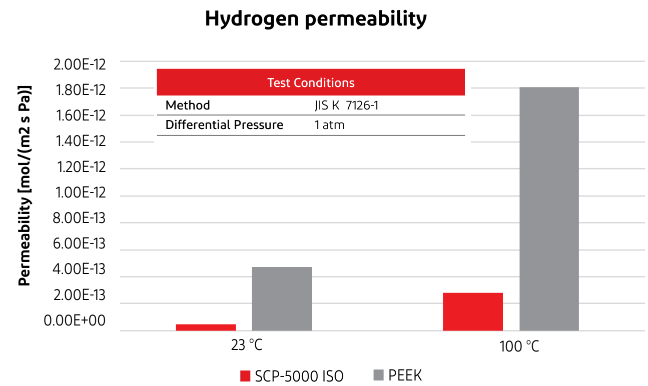




Low and consistent modulus, higher mechanical resistance and low permeability

Hydrogen permeability is a key material property to establish if a polymer can properly store hydrogen over a long period of time. The lower the permeability, the better the material's ability to contain hydrogen and avoid leaking.

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.



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

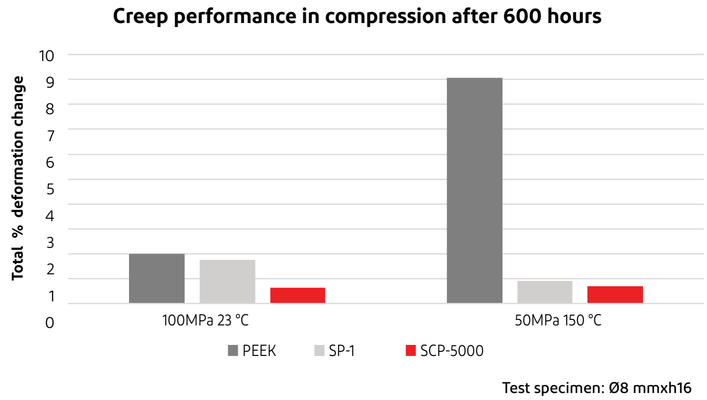
Test conditions	
Method	JIS K 7126-1
Differential pressure	1 atm
Specimen	OD60 x t1 mm

Key properties of Vespel® for Operational Efficiency

Creep, Wear and Friction

Hydrogen leaks largely originate from deformed seals or gaskets. Therefore, materials used in sealing elements should display excellent creep performance.

Vespel® exhibits high dimensional stability, maintaining its sealing performance over a long service lifetime.



Valves require low friction to actuate properly. This is even more important in cryogenic environments of many hydrogen applications. Due to its low coefficient of friction, Vespel® can help reduce actuation force, helping to reduce energy consumption.

In addition, the low wear rate of Vespel® in hydrogen is an important property which helps ensure the long service life of the valve, contributing to less frequent maintenance.

The same characteristics are also beneficial for pumps and compressors in terms of operational efficiency improvement and potential reduction of energy required to operate.

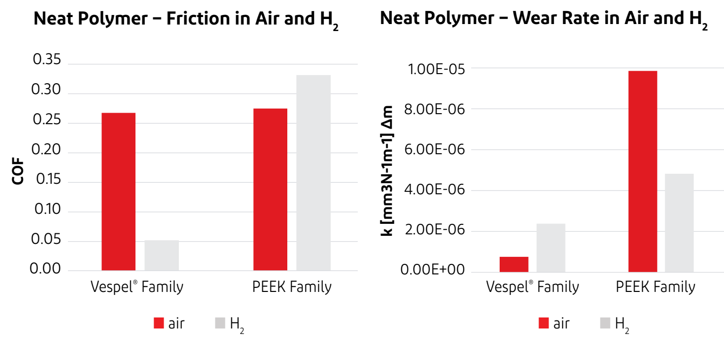


Fig 1.: COF and Wear and friction for Neat polymers of the Vespel® and PEEK Family, data generated by the BAM Bundestanstalt für Materialforschung und –prüfung by Mrs. Theiler, Counterface AISI 304, Ra ~ 0.2 µm, sliding speed v = 0.2 m/s, contact pressure 3 MPa.

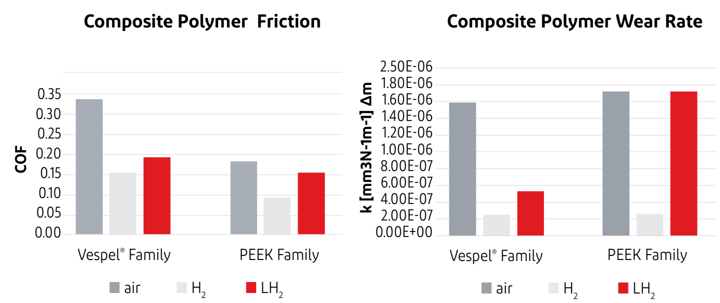


Fig 2: COF and Wear and friction for composite polymers of the Vespel® and PEEK Family, data generated by the BAM Bundestanstalt für Materialforschung und –prüfung by Mrs. Theiler, Counterface AISI 304, Ra ~ 0.2 µm, sliding speed v = 0.2 m/s, contact pressure 3 MPa.

Summary

Vespel® is the answer to the most stringent sealing requirements in hydrogen applications, thanks to its unique blend of thermal, mechanical, and tribological properties.

Challenges in hydrogen applications		Vespel® solutions
Bubble tight sealing from elevated down to cryogenic temperatures	→	**A low and consistent compressive modulus,** and high mechanical resistance, offering exceptional sealing in a variety of typical H_2 conditions
Potential permeability issues during storage, due to low molecular weight of hydrogen	→	**Significantly lower H_2 permeability than materials like PEEK** across a wide range of temperatures
Service life under high loads in wide temperature ranges, from elevated down to cryogenic	→	**Excellent creep performance** at high loads and elevated temperatures, “**soft but strong**” characteristics for sealing at low temperatures
Demanding tribological requirements, efficiency and service life	→	**Low COF in air and hydrogen**, helping to reduce actuation force and improve operational efficiency /reduce energy required to operate
Costly maintenance	→	**Low wear rate** that contributes to lowering the frequency at which components need replacement

Vespel®: the well-suited blend of properties to generate value in hydrogen applications

	Key Vespel® Benefits for H_2 Applications		
Key Vespel® Properties	Tight Sealing	Long Term Performance	Safe Operation
Low hydrogen permeability	X		X
Low creep	X	X	
High mechanical resistance	X	X	X
Low and consistent modulus	X		
Low wear and friction		X	

Key Vespel® Applications		
Valves and Pressure Reducers	Pumps	Compressors
Vespel® S	**Vespel® S and CR**	**Vespel® CR**
Seats	Bearings	Piston Rings
Stem Packing	Wear Rings	Rider Bands
Seat Carrier Seals	Piston Ring	Labyrinth Seals
Hydrogen Receptacles	Bushings	Packing Rings
Connectors		Valve Plates
Propulsion applications, from production to mobility	Propulsion, H_2 transfer, storage, refueling	Production, storage, H_2 transfer, refueling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