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PEKK FOR THE TRANSPORTATION INDUSTRY

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PEKK for the Transportation Industry by Robert Barsotti and Jonathon Hollahan

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TRANSPORTATION

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Polyaryletherketones (PAEKs) are a family of high-performance thermoplastics originally developed in the 1960s by DuPont for the Apollo space program. Since this creation, one-such PAEK — polyetherketoneketone (PEKK) — has been widely used in the aerospace and defense industries. PEKK's outstanding high temperature performance, chemical resistance and flame, smoke and toxicity (FST) profile make it a perfect candidate for multiple applications within the transportation industry.

PEKK chemistry

PAEKs are semi-crystalline thermoplastics marked by excellent chemical resistance and high temperature performance. In this family of polymers, the "backbone" of the monomers are repeating ether groups and ketone groups that provide the high mechanical strength of the polymers (figure 1).

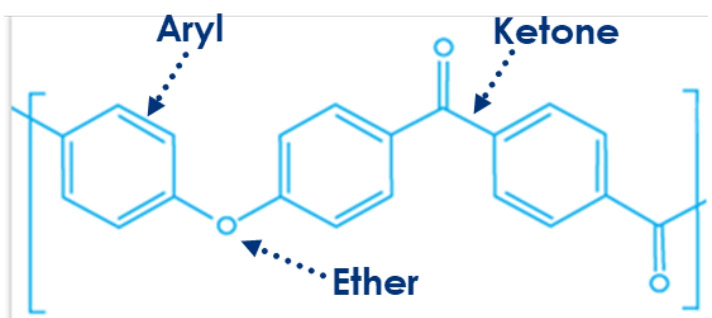

Figure 1: PAEK backbone.

Ketones are stronger than ether groups, so polymers with higher ketone/ether ratios will typically exhibit higher strength. The most common polymer used in the PAEK family has historically been PEEK, which is used across a range of industries in demanding applications requiring strength, chemical resistance and temperature resilience.

PEKK offers many advantages over other PAEK polymers. PEKK exhibits higher strength and modulus compared to PEEK due to its ketone/ether ratio of 2:1 (compared to 1:2 for PEEK). This higher ketone/ether ratio also increases thermal properties of the material, enabling PEKK to be used in applications with higher continuous use temperature requirements. These advantages allow PEKK to compete on a property basis with other high temperature PAEK materials such as polyetherketone (PEK) and polyetherketonetherketoneketone (PEKEKK) while remaining lower cost and providing more processing options and wider processing windows (tables 1 and 2).

	PEKK	PEEK	PEK	PEKEKK
Tg (°C / °F)	160-165 / 320-329	143 / 289	152 / 306	162 / 324
Tm (°C / °F)	305-358 / 581-676	343 / 649	373 / 703	387 / 729

Table 1: Summary of PAEK properties.

Tensile Modulus (GPa/ kpsi) ISO527-1A	3.6 – 4.4 / 522- 638
Compressive Modulus (GPa/ kpsi)	4.2 / 609
Tensile Strength (MPa / kpsi)	120 – 140 / 17 - 20

Table 2: PEKK mechanical properties.

An additional advantage is that PEKK can be a copolymer, composed of straight (**T**erepthalic) and kinked (**I**sophtalic) units. By changing this T:I ratio, it is possible to change the way chains pack together, resulting in a range of crystallization speeds and melting points. PEKK copolymers span a range of behaviors from pseudo-amorphous (super slow to crystalize) to semi-crystalline. The tunable crystallization speed of PEKK allows it to be easily processed with both traditional extrusion and injection molding processing or via more novel processes such as additive manufacturing (both filament based and laser sintering), powder coating, rotomolding, thermoforming or automated tape placement (for composite fabrication). Through PEKK grade selection and adjustment of process parameters, either amorphous or semi-crystalline PEKK can be achieved, depending on the needed performance characteristics of the end use product. PEKK is available in flake, pellets or powders with varying melt viscosities and copolymer ratios to suit the needs of any process. Figure 2 shows a variety of extruded PEKK stock shapes and parts machined from PEKK stock shapes.

PEKK properties and performance

PEKK is known for its high temperature performance, including continuous use temperatures of up to 482°F/250°C. Along with its strong mechanical properties, PEKK also exhibits phenomenal chemical resistance with greater than 90 percent retention of mechanical properties even after a week of soaking in aggressive agents such as toluene or methyl ethyl ketone (MEK), as seen in figure 3.

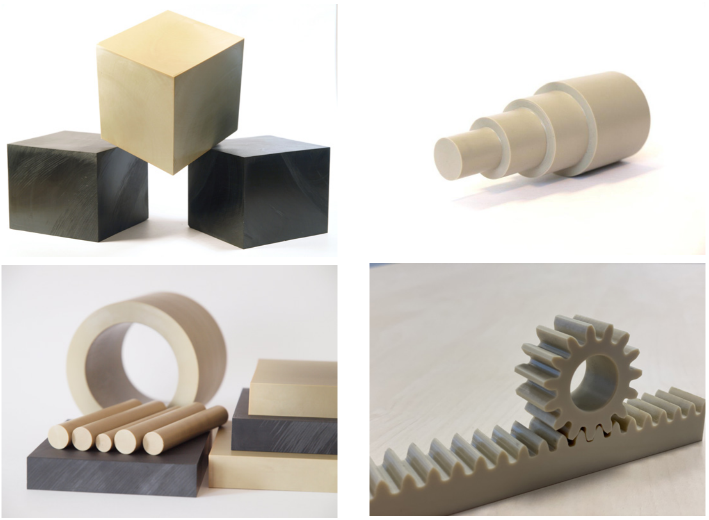

Figure 2: Kepstan® stock shapes and machined parts.

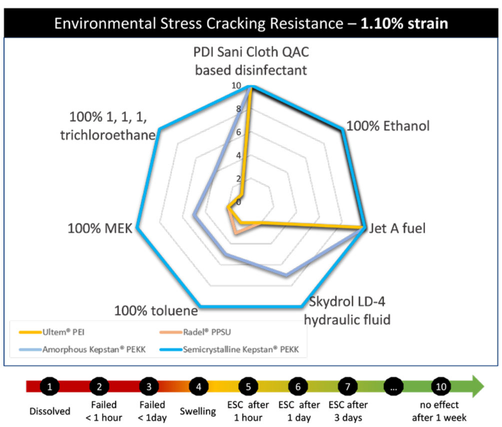

Figure 3: Kepstan PEKK exhibits excellent environmental stress cracking resistance against many solvents encountered in transportation applications

This chemical resistance makes PEKK suitable for demanding environments. PEKK is a halogen-free thermoplastic with excellent FST properties, including a V0 UL94 flame resistance. PEKK also displays excellent wear and friction properties, a low dielectric constant and strong barrier properties to gases such as O_2, CO_2 or H_2S. PEKK is suitable for use in extreme environments. In addition to transportation, PEKK materials can have a significant positive impact in other markets such as chemical processing, defense, oil and gas, and electrical and semiconductor.

PEKK in aerospace applications

PEKK has been used in the aerospace industry for the past two decades due to its outstanding FST profile and strong chemical resistance. Specific testing, as illustrated in figure 3, demonstrates PEKK's resistance to many common solvents encountered in the aerospace industry. PEKK, whether semi-crystalline or amorphous, outperforms polymers such as polyphenylsulfone (PPSU) or polyetherimide (PEI). This performance has allowed PEKK's use in in a variety of aerospace interior and structural applications. 3D printed PEKK has been qualified in aerospace for applications such as overhead ducting. PEKK has also returned to its space exploration roots, being selected as the material for additive manufactured parts on the CST-100 Starliner. Figure 4 shows PEKK 3DP printed parts using both FFF and SLS.

Figure 4: FFF printed amorphous (golden color) and semi-crystalline (beige color) Kepstan® PEKK parts made with Kimya filament (top image courtesy of miniFactory). SLS printed CF reinforced HT-23 part (lower image, powder from ALM produced with Kepstan® PEKK resin, courtesy of DEMGY).

PEKK has exceptional thermal and mechanical properties compared to its PAEK cousins. For example, PEKK has enhanced creep performance compared to PEEK, most pronounced at temperatures between the Tgs of the materials (289°F/143°C and 329°F/165°C for PEEK and PEKK respectively, figure 5). Due to higher crystallization and chain alignment during processing, extruded stock shapes showcase even better creep performance.

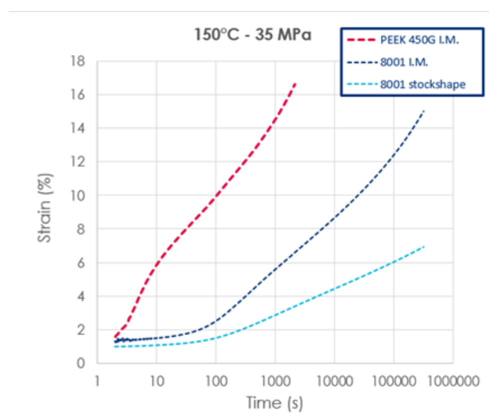

Figure 5: Kepstan 8001 shows lower creep compared to PEEK with even greater advantages for machined stock shape parts.

To evaluate PEKK's performance in petrochemical mining applications, specimens machined from extruded rods were tested according to NORSOK standards (M710). PEKK has a higher modulus and strength compared to PEEK and maintains that advantage over 60 days of exposure to sour gas at elevated temperatures. Other high temperatures PAEKS (PEK or PEKEKK) lose properties rapidly after 10-20 days (figure 6).

PEKK for automotive applications

PEKK has strong potential for use in automotive and mass transit applications due to the aforementioned thermal, mechanical and chemical resistance

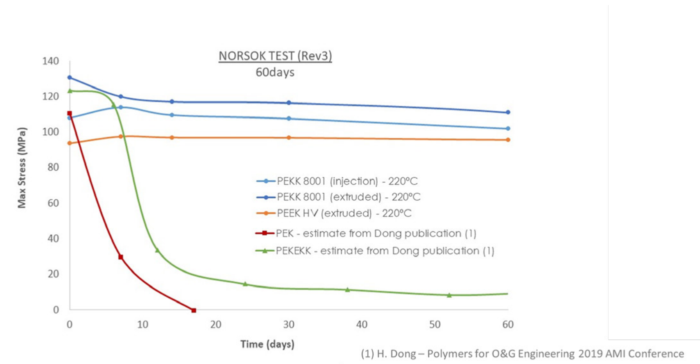

Figure 6: Kepstan 8001 maintains its advantages in strength over other PAEK's during elevated temperature exposure to sour gas.

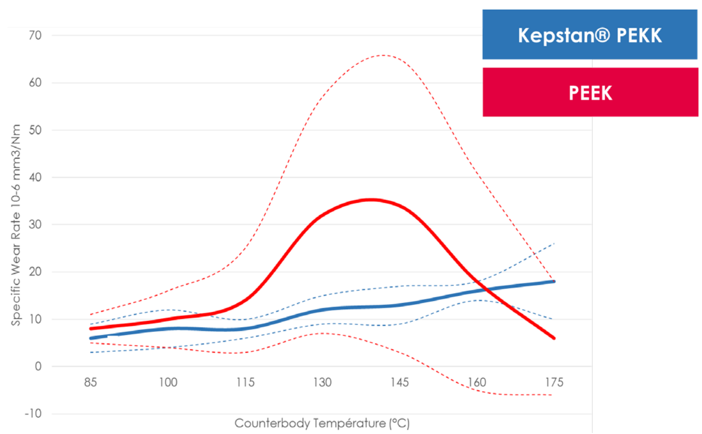

Figure 7: PEKK maintains a more uniform and lower wear rate vs PEEK during block-on-ring testing (applied pressure of 5MPa / 7 kpsi, sliding speed of 1m/s, 3.3 ft/s), with a specific advantage from 239°F/115°C to 320°F/160°C, after which PEEK becomes self-lubricating.

advantages alongside its strong tribological performance and outstanding insulative properties. The wear and friction performance of PEKK makes it an excellent candidate for both injection molded or machined parts in under-the-hood applications. Specifically, transmission seals, which require the highest tribological performance, can be machined from PEKK stock shapes, greatly lowering process costs compared to polymers such as PAI. PEKK demonstrates a lower and more uniform wear rate performance when compared to PEEK (figure 7).

Carbon or glass filled reinforced PEKK grades are available for increased modulus and strength. PEKK can be formulated for specific applications with wear and friction requirements. Formulated PEKK grades have shown performance on par with that of wear and friction PAI formulations (often considered the gold standard), as evaluated using thrust washer testing (ASTM D-3702). PEKK's ability to be melt processed can bring tremendous value when compared to the long cycle times and capital investment needed to process PAI.

Materials with low dielectric constants are becoming increasingly attractive as electric vehicles go to higher power and voltages. Increased partial discharge induction voltages (PDIV) are required to prevent cross-talk amongst electrical components. Both machined components and insulation for magnet wire can benefit from the low dielectric constant of PEKK (as low as 2.6) and its ability to outperform other PAEKs by better maintaining this lower dielectric constant at the elevated temperatures reached during operation. This same insulative performance makes PEKK an excellent candidate for stock shape applications in the electronics and semiconductors markets, including RFI/EMI connectors, wafer/electronic carriers or trays and semiconductor test sockets.

PEKK for thermoformed applications in mass transit

PEKK's tunable crystallinity allows for thermoforming of sheets. This technology brings huge benefits for large area plastic components common in bus, light rail, or rail applications. Amorphous PEKK sheets can be extruded with thickness of 0.012" to 0.118" (0.3 – 3 mm). Sheets are then heated to temperatures above their glass transition temperature for easy forming into complex shapes, with demonstrated draw ratios of up to at least 3. Mold temperatures of 446°F/230-482°F/250°C allow for rapid crystallization. The resulting thermoformed parts have all the excellent thermal, mechanical, chemical resistance and FST properties of semi-crystalline PEKK. PEKK's ability to be easily colored adds additional value in these applications. This thermoforming technology can be extremely valuable in aerospace interior or semiconductor applications where the chemical resistance of PEKK gives it a strong advantage over other amorphous high performance polymers commonly used for thermoformed parts. Figure 8 shows both amorphous and thermoformed PEKK parts, illustrating the achievable draw ratios and intricate features.

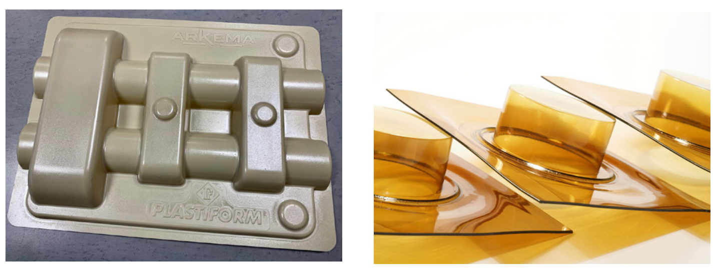

Figure 8. Semi-crystalline (opaque) and amorphous (transparent) PEKK parts made with Arolux® sheet from Westlake Plastics and Kepstan® PEKK resin. Left image courtesy of Plastiform.

In conclusion, PEKK's outstanding physical properties, tunable crystallinity and robust processing options has allowed it a strong history in the aerospace industry with ample promising emerging applications in both mass transit and the rapidly growing field of electric vehicles.

Robert Barsotti, Ph.D. is the global research and development manager for Kepstan® PEKK at Arkema Inc, while Jonathon Hollahan is a business development engineer for Arkema Inc, focused on Kepstan. For more information, contact Robert Barsotti at Arkema Inc at 900 First Avenue, King of Prussia, PA 19406-1308 USA; phone (484)-745-9142, robert.barsotti@arkema.com or www.kepstan.com.

All the data provided in the article is based on studies by Arkema.