TECHNICAL PAPER

VICTREX™ PAEK POLYMERS AND COMPOSITES FOR WIND TURBINE SLIDING BEARINGS

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WIND TURBINE SLIDING BEARINGS: WHITEPAPER

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IMARKET CHALLENGE

To compete effectively in the global energy market, the wind turbine industry continues to seek to provide higher power, increased torque density, improved reliability, and greater worker safety. Sliding bearings based on VICTREX PAEK and PEEK polymers bring the advantages of improved wear performance, reduced size, complexity, and weight compared to traditional metallic bearings. With over 40 years of experience, Victrex can bring expertise to partnerships to support the development of the next generation of sliding bearings-based gear boxes and other components needed for more efficient and reliable wind turbines.

WHY CHOOSE POLYARYL ETHER KETONES (PAEK)?

Through chemistry and material science of PEEK, Victrex has developed sliding bearings with advantaged performance. This has been achieved through:

- **Weight Reduction at Equivalent Stiffness:** 70-85% lower weight at equivalent stiffness compared to some metals
- **Tribological Performance:** ability to perform in hydrodynamic, mixed friction, boundary lubrication, and even dry conditions.
- **Stable Properties:** retention of properties in corrosive, contaminated, and high temperature service conditions.
- **Lower Cost:** savings in labor, time, and money through scalable manufacturing, longer service life, and ease of replacement..

VISION: LOWER COST, LIGHT WEIGHT PEEK SLIDING BEARINGS

PEEK-based sliding bearings have been able to increase reliability and service life, decrease weight, and improve operational efficiency for adjacent markets. Through collaboration with Victrex, these benefits might also be realized for critical wind turbine components (i.e. gearboxes) as well.

An automotive OEM achieved reduced cost and an 80% mass reduction for a torque converter while maintaining operating performance and efficiency. This was achieved by replacing a traditional metal roller bearing with a full PEEK bushing comprising fewer but also lighter weight components (Figure 1).

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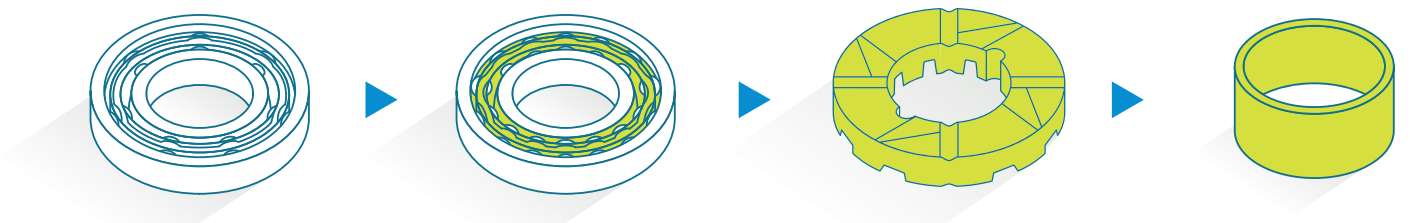
Working together from concept stage to product launch, we can go beyond small measures and truly create solutions that will give our customers real competitive advantage.



METAL BEARING WITH PA CAGE

METAL BEARING WITH PEAK CAGE

Replacing a PA bearing cage with PEEK allowed

- a higher number of balls, thus
- higher loads in smaller spaces

FULL PEAK BUSHING (RUNNING CHANGE)

Designing a full plastic bearing as a running change enabled

- reduced weight and
- lower part cost at same loads in the same space

OPTIMISED FULL PEEK BUSHING

Partnering with Victrex at early concept stage supports optimised part design and allows maximum benefits, e.g.

- reduced system space
- lower part cost while maintaining the same load

We understand the characteristics and behaviours of PEEK right through the manufacturing process – help our customers achieve new ways of solving complex challenges – true innovation.

Figure 1. Transition from roller to journal bearings with VICTREX PEEK technologies.

PEEK formulations typically have a density of 1.3-1.53 g/cm^3 which is up to about 70% lighter than many steels, 82% lighter than Babbitt metals, and 85% lighter than certain bronze alloys (Figure 2).[1] Lighter weight components reduce angular momentum which could result in energy savings and potentially more compact designs. If comparable performance is achieved, turbines with greater torque density could be realized in part due to PEEK components.

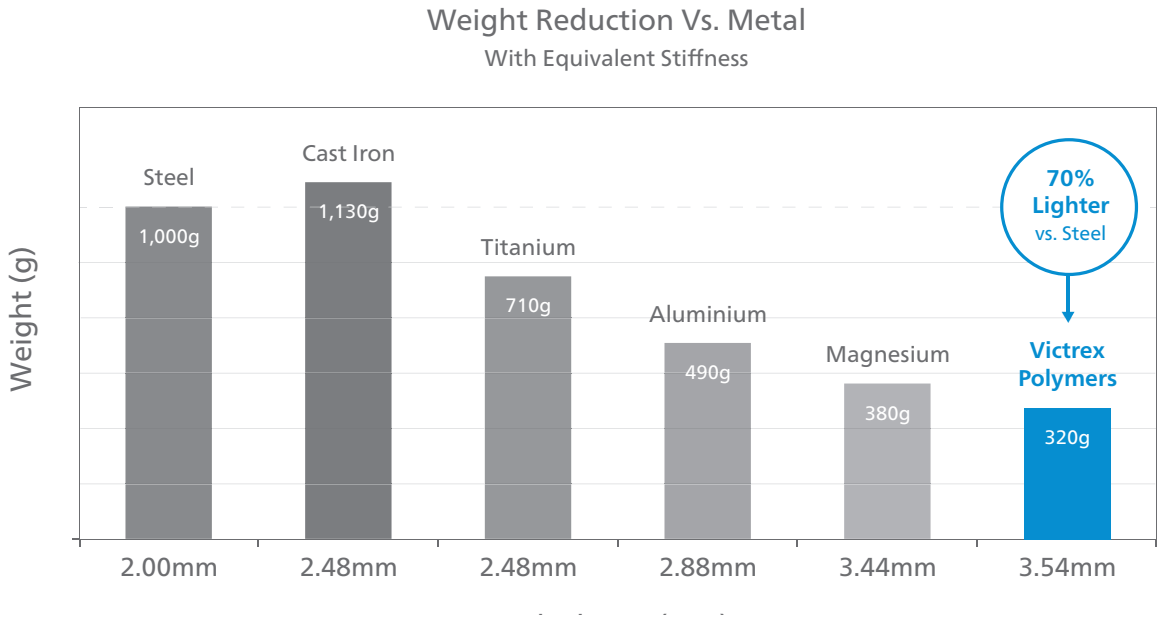


Figure 2. Improved energy efficiency through weight reduction.

TRIBOLOGICAL PERFORMANCE

In regular operation, bearings systems in wind turbines can experience a broad range of operating pressures and velocities. At sufficient and steady velocity, hydrodynamic lubrication can provide sufficient lift to separate opposing bearing surfaces, however that is not always present. *Mixed lubrication* can be present at intermediate velocities and changing wind speed and direction resulting in wear due to contact of asperities of opposing surfaces.[2] Startup and shutdown can result in direct contact of bearings surfaces described as *boundary lubrication* which can result in severe wear.[3]

Consequently, engineers need to design for all lubrication regimes. Achieving low friction and high resistance to wear is essential to the reliability and efficiency of bearing applications.

In thrust washers, bushings and bearing cages, VICTREX PEEK has a proven track record in delivering the following[4]

- Stable coefficient of friction (CoF) as low as 0.05 in dry conditions
- Excellent wear performance across a range of pressure and velocity scenarios
- High compressive strength over a wide temperature range to support component miniaturisation respectively increased loads
- High reliability due to excellent emergency running properties - no sudden blocking of bearing
- Improved noise, vibration, and harshness (NVH) in plain bearings without multi-frequency noise and vibration spectrum of rolling element bearings

ROBUST PERFORMANCE OF VICTREX PEEK SOLUTIONS

To achieve reliable performance, the bearing materials should also be able to perform in the various environments and service conditions where the turbine is installed. In the Oil & Gas market VICTREX PEEK been recognized for its performance at high temperatures and pressures and in corrosive conditions served for over 40 years.

HIGH TEMPERATURE AND PRESSURE PERFORMANCE

VICTREX PEEK solutions have provided stable performance in temperatures ranging from -196°C (-321°F) up to 260°C (500°F) with the capability of withstanding differential pressures up to 207 MPa (30,000 psi).[5] These properties may enable bearings to survive the high loads present in transitional states of operation in bearings for wind turbines.

CORROSION RESISTANCE

VICTREX PEEK is generally recognized as minimally absorbing of water (0.5% by weight[6]) and resistant to hydrolysis. Consequently, properties should be largely maintained in such environments. VICTREX PEEK-based solutions also provide durability even when operating in corrosive elements such as hydrocarbons, seawater, and harsh gases such as H2S that can embrittle many metals (Figure 3). Offshore installations where salts and other chemicals typically corrode metals may benefit from replacement with PEEK.

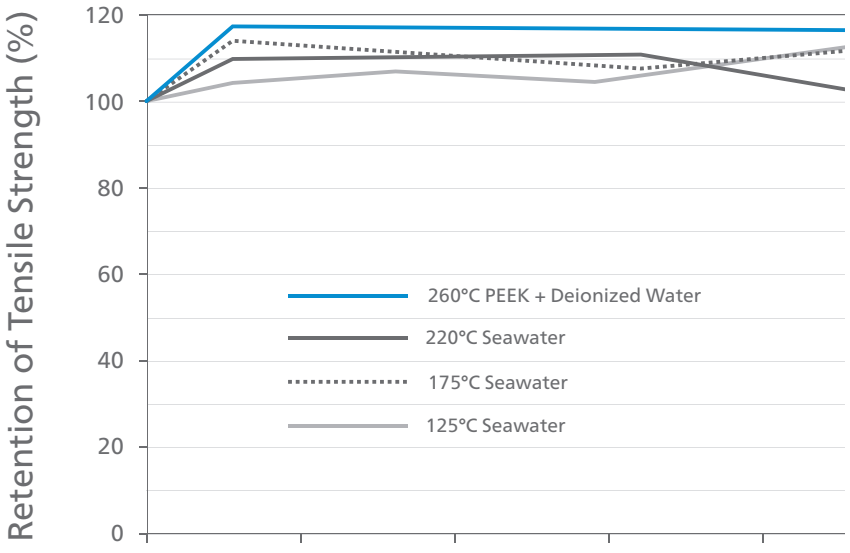


Figure 3. Retention of tensile strength of VICTREX PEEK after aging in sour seawater (NORSOK M710 Ed 3 method).[7]

ADDITIONAL BENEFITS

In addition, VICTREX PEEK exhibits a broad spectrum of characteristics that may improve operational efficiency in the wind industry (Figure 4).

EASE OF MANUFACTURE AND PROTOTYPING

Because VICTREX PEEK is a thermoplastic, it can be manufactured into parts with existing melt processing technologies such as injection molding, compression molding, and machining. These processes are well-established, scalable, and cost effective. Also, PEEK is compatible with emerging additive manufacturing technologies ("3D printing"). As a result, bearings engineers may enjoy design freedom and rapid prototyping to potentially realize faster product development cycles.

NONTOXIC

VICTREX PEEK polymers are high in purity and nontoxic. Used in dental and healthcare industries, minimal extractables and leachable support human health in medical devices including implants. Workers contact with new or worn PEEK parts should have less risk compared to some white metals which can contain lead, antimony, and other potentially toxic substances.[8, 9]

Figure 4. Advantages of VICTREX PEEK solutions.

COMPARISON OF WEAR PERFORMANCE OF PEEK AND BABBITT METALS IN SLIDING BEARINGS

Industrial bearings manufacturers implemented PEEK in sliding bearings (Figure 5):

(a) (b)

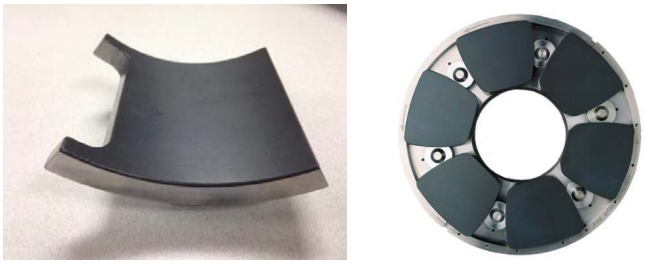


Figure 5. PEEK-based (a) journal bearing pad and (b) thrust bearing (Reference: Jie Zhou, "Temperature Monitoring of PEEK Bearings", Society of Tribologists and Lubrication Engineers Conference, Las Vegas, May 15-19, 2016.)

FORMULATION FOR TRIBOLOGICAL PERFORMANCE

Because PEEK is thermoplastic, its wear performance can be readily adjusted to maintain bearing performance even in unlubricated, dry conditions. This has achieved by formulation with additives including solid lubricants (PTFE, graphite…) and reinforcing agents such carbon fiber for strength and fatigue resistance. Maximum pressure·velocity (PV) values as high as about 7.8 MPa·m/s have been achieved.[10] Combined with PEEKs non-hydroscopic nature (~ 0.5% water absorption), these characteristics tend to be more robust than more hygroscopic polymer systems which can soften and swell in wet environments.

BROAD PERFORMANCE WINDOW

For wind turbine bearings, the ability to formulate for performance and relatively high heat resistance as measured by heat deflection temperature (HDT)[11] gives engineers more design options to accommodate different pressures and velocities. Yuki has previously shown that PEEK in a thrust bearing design can withstand higher bearing surface temperatures compared to certain Babbitt metals. This resulted in the ability to perform at higher specific pressures (Figure 5):

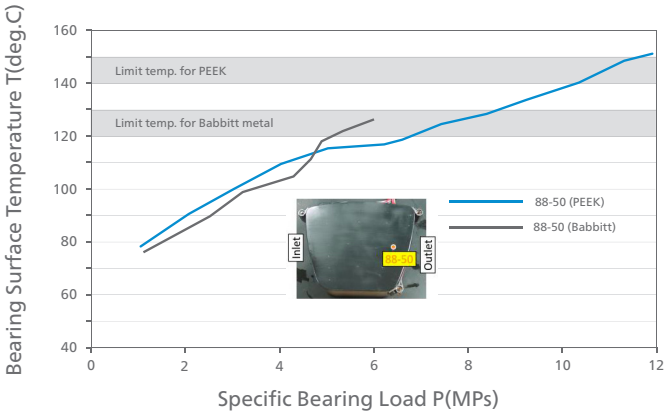


Figure 6. Thrust bearing surface temperature (PEEK vs Babbitt) as a function of specific bearing load (Reference: Sumi Yuki, et al. "Development of thrust bearings with high specific load." ASME Turbo Expo 2014: Turbine Technical Conference and Exposition, American Society of Mechanical Engineers, 2014.)

In another comparison, Zhou found a PEEK system to endure approximately 50% higher maximum pressure at 11000 rpm in the thrust bearing design (Figure 6) compared to a Babbitt metal. At 9.6 MPa, the Babbitt bearing exhibited distress in the form of creep and lubricant coking on the trailing edge. In contrast, the PEEK system was able to perform to 14.5 MPa at 11000 rpm with limited deformation.

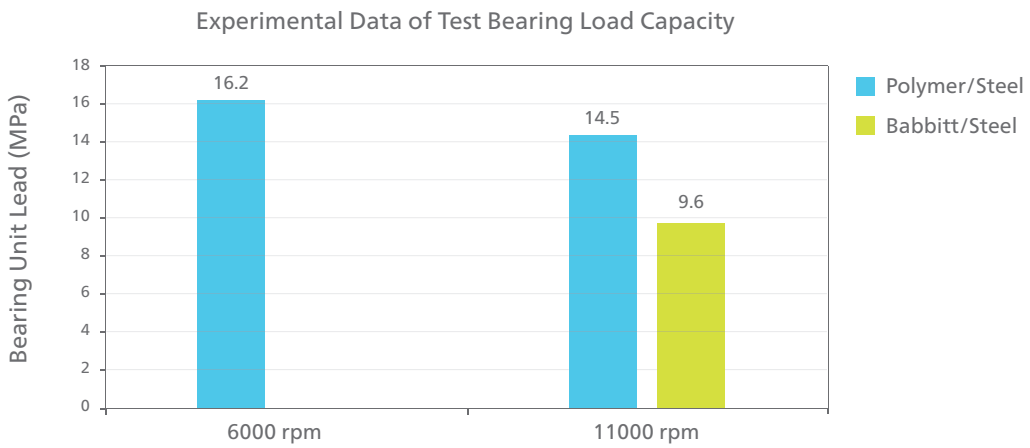


Figure 7. Load capacity of PEEK vs Babbitt/steel thrust bearing at different speeds (references: Zhou, Jie, et al. "Experimental Performance Study of a High Speed Oil Lubricated Polymer Thrust Bearing." Lubricants 3.1 (2015): 3-13; Zhou, Jie, et al. " Performance of a PEEK-Lined Tilt Pad Thrust Bearing at High Speeds with Oil Lubrication." 14th EDF/Pprime Workshop 2015.)

CONCLUSIONS

Application of VICTREX PEEK in light weight sliding bearing has the potential to perform at higher pressures and bearing surface temperatures compared to Babbitt metals. As a result, PEEK-based bearings may enable a broader range of design and the opportunity for improved performance.

Hypothesized scenarios include

- Greater Reliability at the Similar Specifications: A PEEK sliding bearings used at conditions further from its physical limitations should have a higher safety factor.
- Greater System Reliability with More Compact Designs: Utilizing PEEK's performance to realize more compact and lighter weight designs should lessen stress on adjacent components. Reliability to other systems (brakes, gears, other bearings...) may improve as well due to lower loads.
- Increased Torque Density: Higher rated performance could result in usage in a turbine rated to higher power output.

Along with these potential benefits, VICTREX PEEK is known for performing in challenging conditions (extremes temperatures, corrosive environments, high mechanical loads, and mixed lubrication) that may be encountered in service as a sliding bearing. Because PEEK is thermoplastic, it may be formulated with components that allow for further control of mechanical and wear performance. These characteristics are present from prototyping (i.e. 3D printing) to commercial scale manufacturing.

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