Additive Increases Fluoropolymer Wear Resistance

Without degrading other properties

$PPSO_2$ is used in the PTFE outer cover for push-pull cable mechanisms. In effect, the fluoropolymer tube serves as a linear bearing to reduce friction between the stationary cover and moving cable.

Linear bearings and other wear parts are commonly made from fluoropolymers to take advantage of the materials' low-friction properties and chemical resistance. Based on recent laboratory tests with fluoropolymer bearing materials, adding polyphenylene sulfone ($PPSO_2$) to the resin blend improves long-term performance, especially under high-temperature and high-load conditions.

The additive helps fluoropolymer bearings last longer, handle higher loads at higher temperatures, and resist cold flow under higher preloads. Moreover, these gains are achieved without compromising the chemical resistance and/or lubricity of the bearing. Those properties may suffer when fiber reinforcements or additives such as polyarylate (PAR) or polyimide (PI) are used. The same $PPSO_2$ additive also improves bonding of fluoropolymers to metallic reinforcement rings.

The findings by researchers at the University of Erlangen-Nurenberg in Germany have important implications for designers of linear actuators, low-speed transmissions, or gearboxes that incorporate linear, thrust, or plain rotary bearings. Drive and bearing designers can, for example, take full advantage of the exceptional lubricity and chemical resistance of PTFE and other fluoropolymers in higher-load and preload situations.

From a friction/lubricity standpoint, neat fluoropolymers have long been accepted as an ideal nonlubricated bearing material for low-speed applications at moderate temperatures. They are maintenance-free, offer extremely low coefficients of friction without lubrication, and are immune to degradation by most chemicals. Those properties explain why fluoropolymers have shown

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up so widely in linear bearings such as push-pull cable jackets.

The down side is that unsupported fluoropolymer deforms over time under sustained loads, a property known as cold flow. Fluoropolymer bearings are also prone to wear under continued use. These shortcomings have limited the wider use of PTFE and other fluoropolymers in higher load and more critical applications.

Past remedies have included reinforcing fibers and PAR or PI additives. Each has improved the life and expanded the operating envelope of fluoropolymer bearings, but each has shortcomings. Reinforcing fibers increase resistance to wear and cold flow, but only at the expense of lubricity. Fibers on the bearing surface can also mar metal parts that move against the fluoropolymer, increasing friction, heat, and wear. Likewise, PAR and PI additives improve wear and cold-flow resistance, but only at the expense of the chemical resistance of the bearing as a whole.

This is why linear bearing and transmission design engineers have sought a fluoropolymer bearing material offering greater resistance to both wear and cold flow while retaining the lubricity and chemical immunity of neat fluoropolymer.

Ceramer $PPSO_2$ is derived from the linear polyphenylene sulfide (PPS) polymer known for its thermal stability and chemical resistance. A closer look at this additive will clarify why it offers such promise for improving fluoropolymer bearing performance.

$PPSO_2$ is a hard (Vickers hardness 28HV), partially crystalline resin with a glass transition temperature of 360C (680F). Compressive strength is 275 MPa, and yield stress is 170 MPa. Chemical resistance is nearly equivalent to that of PTFE; there is no known solvent. As with PTFE, the melt temperature of $PPSO_2$ is higher than its decomposition temperature, so neat parts of Ceramer $PPSO_2$ must be hot-press molded and not melt-processed. Hot-pressing pressures range from 10 to 20 ksi at temperatures from 425 to 435C.

Particle size distribution is 20 µm average, 50 µm maximum. The fine $PPSO_2$ particles are essentially spherical with a very rough surface, providing about 10 m^2/g of surface area for good mechanical bonding to adjacent material. The fine particles allow the additive to be compounded easily in the base resin much like other commonly used fillers.

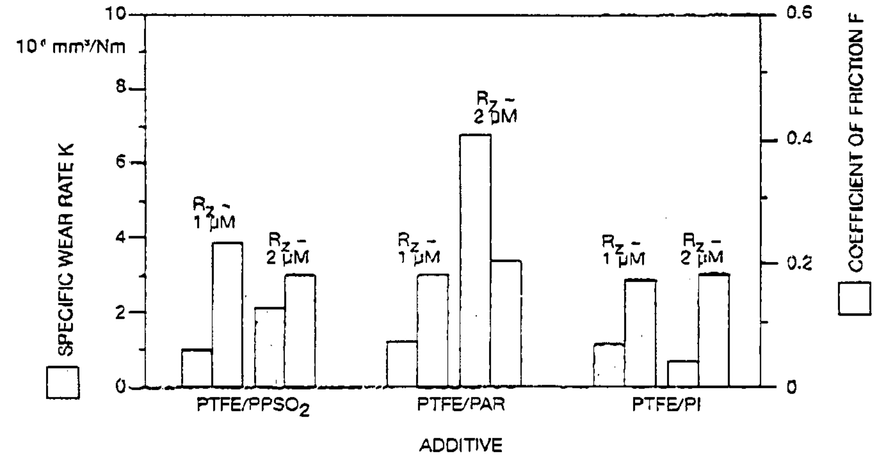
Scanning electron micrograph of PPSO2 particles shows the surface roughness that provides good mechanical bonding to fluoropolymer materials.

It is the combination of uniform particle size and shape, good gripping surface, and temperature and chemical resistance that makes $PPSO_2$ such a promising fluoropolymer bearing additive. Polyphenylene sulfone can also be a cost-effective wear retarder. PAR costs about 50% more per pound than $PPSO_2$. PI is about twice the price of the new additive.

Wear Testing

To find out whether $PPSO_2$ would fulfill its promise, scientists in Germany recently ran comparative wear and friction tests of PTFE specimens loaded with between 5 and 20% PAR, PI and

COMPARISON OF SPECIFIC WEAR RATES OF PTFE FILLED WITH $PPSO_2$, PAR, AND PI ADDITIVES



$PPSO_2$. The same standard pin-on-disk friction/wear testing apparatus performed all the tests under identical conditions.

Testing involves spinning a sample disk under controlled conditions of temperature and velocity while a hard pin bears down on it under a known load. Periodic measurements of material lost due to the load quantify a wear rate. Tests were run at 0.5 and 4.0 m/sec surface velocities and 1 and 5 MPa pin pressures. All test specimens were manufactured under processing parameters corresponding to those used to make commercial quantities of fluoropolymer bearing material with 10% additive levels.

To measure the effect of surface roughness on service life, test materials were tested against two different levels of surface roughness.

Against smooth and rough specimens, the $PPSO_2$ demonstrated about twice the wear resistance of PAR. Against the smoother samples, wear resistance of $PPSO_2$ closely matched that of PI, but in contact with rougher specimens, PI outlasted it. Coefficients of friction, or lubricity, were comparable for all additives in all specimens. Note that, under these conditions, plain PTFE would wear so quickly that data could not even be collected.

When comparing these results, remember that $PPSO_2$ has superior chemical and temperature resistance to both PAR and PI, especially resistance to sulfuric acid. Also, the smaller particle size of $PPSO_2$ relative to the PAR and PI material evaluated creates a smoother bearing surface.

To compare heat resistance of bearings with various $PPSO_2$ loadings, test temperatures were varied between 25 and 250C (77 and 482F). As a reference, note that unfilled PTFE starts to flow and can no longer be studied at 150C (300F). Elevated-temperature testing showed that $PPSO_2$ increases the service temperature limits of PTFE bearing materials into the 200–250C (392–482F) range. The exact service temperature limit will depend on loads and $PPSO_2$ content.

The study also provided load, temperature, and other guidelines for use of $PPSO_2$ additives in fluoropolymer bearing materials. For low-load applications, a 10% additive content by weight is probably adequate. For higher loads or contact velocities, a better starting point is 20%.

For operating temperatures in the 220–250C range (428–482F),

$PPSO_2$ content should be about 10%. For plastic-metal combinations, designers should keep hardness of the metal above 50 RC. With anything softer, roughness peaks can break off and embed themselves in the plastic, acting as an abrasive in the bearing.

Adding as little as 5% $PPSO_2$ can significantly improve PTFE bearing life when loads are in the 5-MPa range or higher.

Typical Applications

Several manufacturers have already taken $PPSO_2$-filled fluoropolymers beyond testing and into the commercial application stage.

One example is the cover lining for a push-pull cable mechanism such as those typically used in automotive, industrial, and lawn and garden equipment applications.

In effect, the fluoropolymer tube serves as a linear bearing to reduce friction between the stationary cover and moving cable. In such cables, the addition of $PPSO_2$ to PTFE paste extrusion powders increases life dramatically.

In one test, unlubricated push-pull cable jackets filled with 7% branched polyphenylene sulfide (PPS) rubbed through after only about 30,000 cycles. Cables containing the same amount of $PPSO_2$ were still intact after one million cycles. Reliable, low-friction performance is essential in such applications.

Another example is a pump housing made of the fluorothermoplastic destined for extremely corrosive service. PFA reinforced with 30% $PPSO_2$ improved both the structural strength and chemical resistance in a single component. The additive enhanced both hardness and yield strength of the housing.

Linear drives, transmissions, and actuator mechanisms have broad requirements for bearings capable of handling low speeds and high loads with zero maintenance. Examples are found in control linkages, clutch and shift mechanisms, shaft containment and housings. Self-lubricated fluoropolymer bearings have proven successful in thousands of such applications. Early tests of Ceramer $PPSO_2$ in combination with other high-performance polymers such as PEI, PES, and PEEK have shown benefits similar to those demonstrated with fluoropolymers. An FDA compliant grade, and a high-purity grade to meet semiconductor industry standards are expected in 1998. With $PPSO_2$ improving wear resistance, dimensional stability and cold-flow resistance, fluoropolymer bearings are ready to take on even more severe-service applications.

For more information on $PPSO_2$ additives, **circle 420.** ■