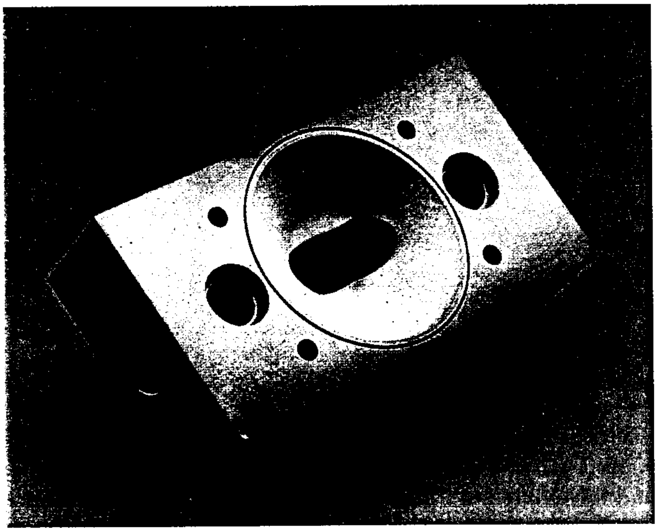
Low friction and high wear resistance can be achieved in plastics components by the use of suitable friction- and wear-reducing fillers. Polyphenylene sulphone (PPSO$_2$) appears to be a particularly effective filler for improving the friction and wear properties of polytetrafluoroethylene (PTFE).



Pump housing made from PFA reinforced with PPSO$_2$
Photo courtesy of Venus, Heidenheim

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Wear-Resistant PTFE Compounds

Friction and Wear of Polyphenylene sulphone filled PTFE

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Tribologically stressed parts are increasingly being produced from plastics, not only to cut costs but also for technical reasons. Low friction and high wear resistance can be achieved in plastics components through suitable friction and wearminimizing fillers. This makes particular sense if savings in material, manufacturing or design costs can be obtained. The application limits of tribologic-stressed parts are often determined by the temperatures arising on the sliding surface or in the component and the increased wear and reduced load-carrying capacity associated with this. The thermal and chemical stability of the fillers should not be lower than those of the matrix materials.

Polyphenylene sulphone (PPSO$_2$) appears to be a particularly suitable filler for tribologic-stressed parts, since it possesses high rigidity and hardness, is very wear and chemical resistant and also has high heat resistance. Studies show how the use of PPSO$_2$ as a filler influences the friction and wear properties of polytetrafluoroethylene (PTFE).

Manufacture of PTFE Compounds

PTFE powders (grade: Hostaflon TF 1750, manufacturer: Dyneon) were mixed with different proportions of PPSO$_2$, cold pressed into cylinders with an outside diameter of 45 mm and then sintered.

To enable a better assessment of the tribological properties of the PTFE/PPSO$_2$ compounds to be made, PTFE compounds containing 10 % of well-established organic fillers were produced for comparative studies, e.g. polyarylate (PAR; grade: Ekonol, manufacturer: Kennecott, Sanborn/New York [4] and polyimide (PI; grade: Sintimid P84, manufacturer: Sintimid Hochleistungskunststoffe, Lenzing/Austria [5]). The processing parameters corresponded to those used in the manufacture of the PTFE/PPSO$_2$ compounds containing 10 wt.-% PPSO$_2$. The particle size distributions of the organic fillers are shown in Fig. 3. With regard to chemical resistance, PAR and PI differ from PPSO$_2$ mainly in their lower resistance to sulphuric acid [3, 4, 5].

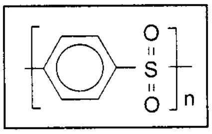

Fig. 1. Structural formula for polyphenylene sulphone (PPSO$_2$)

Friction and Wear Properties

For comparison of materials under different thermal and tribological stresses, a pin-on-disc machine (Fig. 4) is suitable [6, 7]. The tribological properties of the materials stud-

Polyphenylene Sulphone (PPSO$_2$)

PPSO$_2$ (Fig. 1) is a partially crystalline plastic (type: Ceramer, manufacturer: Hoechst) and has a glass transition temperature (T_g) of approx. 360 °C. The melting range of the material is above the decomposition temperature and so PPSO$_2$ cannot be melt processed but must be hot press moulded. Initially the manufacturers are concentrating on the use of this material as a filler for plastics, e.g. to improve their friction and wear resistance or metallizability.

The average particle size (d$_{50}$ value) of PPSO$_2$ is about 20 µm. The maximum particle size (d$_{100}$ value) is less than 50 µm. The specific surface area according to BET [1, 2] is about 10 m^2/g. The PPSO$_2$ particles are spherical and have a very rough, fissured surface (Fig. 2). This enables them to lock tightly into the matrix material.

PPSO$_2$ is recommended as a filler for improving the wear properties of plastics because it has very high compressive strength and high hardness (Table 1). Its chemical resistance is comparable with that of PTFE [3]. Even at relatively high temperatures, no solvent is known for PPSO$_2$.

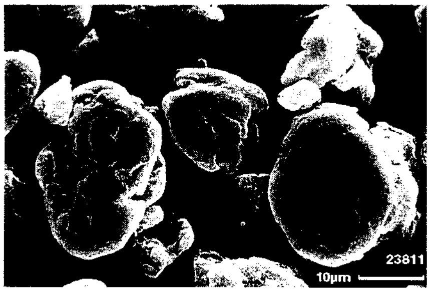

Fig. 2. PPSO$_2$ particles under a scanning electron microscope

Table 1. Properties in the compression test (based on DIN ISO 604) and Vickers hardness (DIN 50133) determined on sintered PPSO$_2$ test specimens

Properties		Characteristic values
Modulus of elasticity in compression	MPa	4000
Yield stress in the compression test	MPa	170
Compressive strength	MPa	275
Vickers hardness		28 HV 1/60

ied can be described according to DIN ISO 7148 [8] by the linear wear rate $w_{l/s}$, the specific wear rate k and the coefficient of friction f.

In plastic-metal combinations, irrespective of the type of plastic, the Rockwell hardness of the metal partner should always be greater than 50. With low surface hardness, roughness peaks can break off, become partly embedded in the plastic sliding surface and act as an abrasive so increasing metal and plastic wear [7, 9]. In addition, in such combinations, the frictional and wear properties of the plastic depend, to a considerable extent, on the surface roughness of the metal partner. For each plastic, there is an optimum surface roughness of the metal partner (R_z) that ensures uniform sliding (stick-slipfree movement) with minimum plastic wear [10].

Fig. 5 shows the effect of PPSO$_2$ content on the specific wear rate k and the coefficient of friction f for different surface roughness values of the metal partner with a contact pressure loading of 5 MPa and a velocity of 0.5 m/s. Under these conditions, unfilled PTFE wears so severely that its use is no longer sensible from a technical viewpoint. Irrespective of the surface roughness of the metal partner, the specific wear rate is significantly reduced by the addition of 5 % PPSO$_2$ to the PTFE. At an average roughness height of $R_Z \sim 2$ µm, the specific wear rate with a content of 5 to 10 % PPSO$_2$ is about twice as high as at $R_Z \sim 1$ µm, and with 20 % PPSO$_2$ even three times as high. The dry friction coefficient is only minimally influenced by the addition of PPSO$_2$ and surface roughness and shows the typically low values of about 0.2 for PTFE compounds.

For comparison, 10 % PPSO$_2$, PAR and PI were added to the PTFE. At $R_Z \sim 1$ µm there was no difference either in specific wear rate or coefficient of friction (Fig. 6). The same applies to the coefficient of friction at $R_Z \sim 2$ µm. On the other hand, the specific wear rate at $R_Z \sim 2$ µm was reduced to one-third by the addition of PI while with PAR it was virtually tripled.

The specific wear rate k is a value related to the sliding path and the perpendicular force. However, wear does not always increase proportionally with the perpendicular force. For this reason, the linear wear rate $w_{l/s}$ is used to describe wear properties (Fig. 7). By increasing the velocity from 0.5 m/s to 4 m/s, wear is sharply increased and at 5 wt.-% PPSO$_2$ reaches more than 200 µm/km. The high wear rates of unfilled PTFE will not be further considered since there would be little point in this from a technical perspective. Through the addition of at least 5 wt.-% PPSO$_2$, the properties of PTFE are so improved that at sliding speeds of up to 0.5 m/s good wear properties are obtained. For higher wear rates, the addition of at least 10 wt.-% PPSO$_2$ is required. With 20 wt.-% PPSO$_2$, PTFE can be used under very severe conditions of v = 4 m/s and p = 5 MPa.

To evaluate the heat resistance of the compounds, trials were carried out with sliding surface temperatures of 200 °C and above (Fig. 8). At temperatures above 150 °C and a contact pressure of 5 MPa, unfilled PTFE starts to flow and can no longer be studied. Through the addition of PPSO$_2$ to the PTFE, the temperature limit can be raised to above 200 °C. In the range between 220 and 250 °C, the PTFE matrix is greatly softened and wear increases significantly. At even higher temperatures, the specimens are deformed by the reduction in load-carrying capacity and further trials are not possible.

Potential Applications

The wear resistance of PTFE can be significantly increased by the addition of PPSO$_2$. This also significantly reduces the wear susceptibility of PTFE to rough surfaces. Nevertheless, the average roughness height R_Z of the metal sliding partner should not exceed

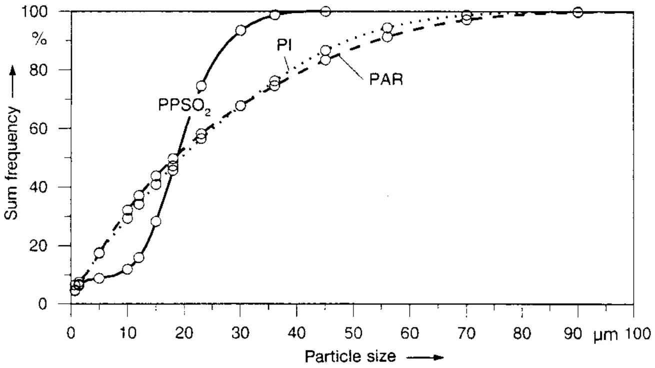

Fig. 3. Particle size distribution of the fillers studied: PPSO$_2$, PI (polyimide) and PAR (polyarylate)

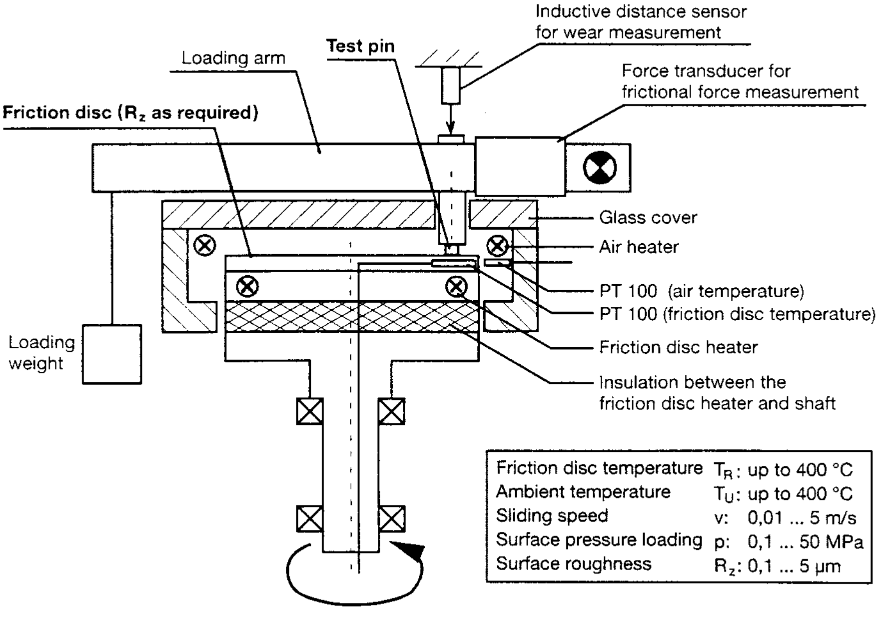

Fig. 4. Schematic diagram of the pin-on-disc-machine with controllable friction-disc and ambient temperature

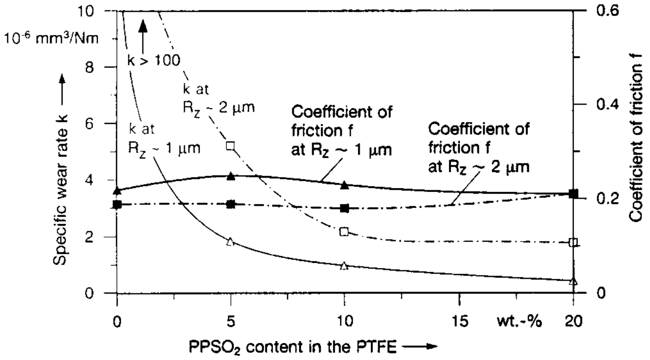

Fig. 5. Specific wear rate k and coefficient of friction f of the PTFE/PPSO$_2$ compounds in the pin-on-disc-machine (conditions: p = 5 MPa, v = 0.5 m/s, T = 23°C, technically dry)

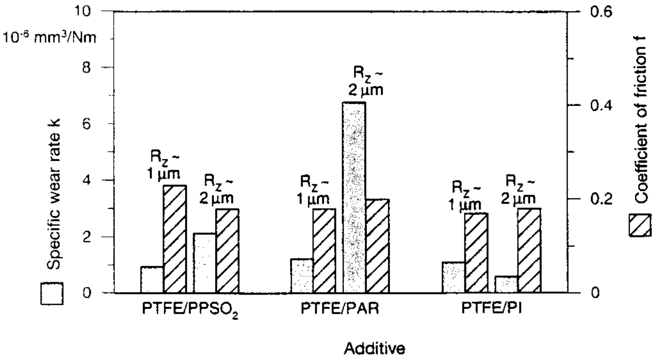

Fig. 6. Specific wear rate k and coefficient of friction f of PTFE + 10% PPSO$_2$, PTFE + 10% PAR and PTFE + 10% PI (conditions: $R_Z \sim 1$ and ~ 2 µm, p = 5 MPa, v = 0.5 m/s, T = 23°C, technically dry

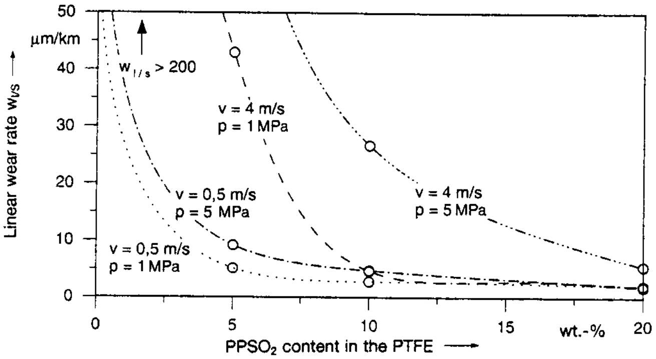

Fig. 7. Linear wear rate $w_{l/s}$ of the PTFE/PPSO$_2$ compounds as a function of contact pressure p and velocity v in the pin-on-disc-machine (conditions: $R_Z \sim 1$ µm; technically dry)

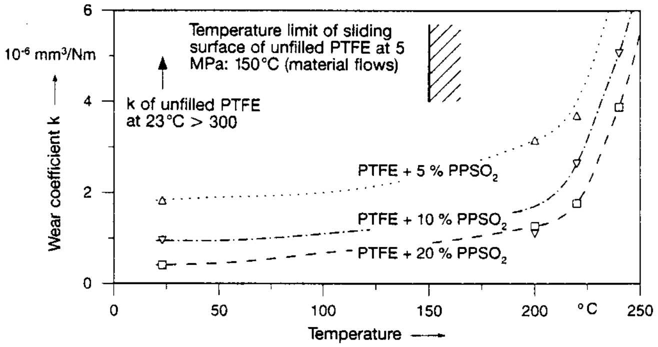

Fig. 8. Specific wear rate k of the PTFE/PPSO$_2$ compounds as a function of sliding surface temperature in the pin-on-disc-machine (conditions: $R_Z \sim 1$ µm, v = 0.5 m/s, p = 5 MPa, technically dry)

the normal values for PTFE of 1.5 µm. Under such conditions, PTFE/PPSO$_2$ compounds have wear properties comparable to those of PTFE/PI and PTFE/PAR compounds and in some cases better, while the chemical resistance of the filler is higher. In addition, the smaller particle size of PPSO$_2$ makes it possible to achieve better surface quality.

With the addition of at least 20 wt.-% PPSO$_2$, PTFE can be used at high contact pressure (5 MPa) and high velocity (4 m/s). At low loads (v < 0.5 m/s; p < 5 MPa), the addition of 10 wt.-% PPSO$_2$ is sufficient. The temperature limit of sliding surface for PTFE/PPSO$_2$ compounds is between 220 and 250 °C, depending on the load. In this range, the PPSO$_2$ content should be at least 10 wt.-%. The friction coefficient is always between 0.2 and 0.3 under technically dry conditions.

According to the specific properties of PTFE-compounds different applications are possible. *Push-pull cables* are used to sheathe steel cables in the manufacture of Bowden gears. Because of the high heat and wear resistance of PPSO$_2$, these cables are now produced from PTFE/PPSO$_2$ compounds (Fig. 9). In comparison with the Bowden gears previously used with push-pull cables made from PTFE/PPS compounds, the wear-dependent service life is increased 30 times.

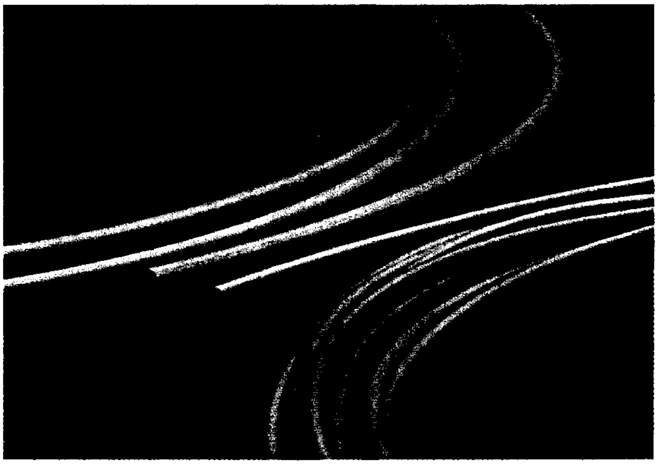

Fig. 9. Push-pull cable made from PTFE paste extrusion powder (type: Norslide, manufacturer: Norton Pampus, Willich) reinforced with PPSO$_2$ (type: Ceramer, manufacturer: Hoechst) Photo courtesy of Nortslide, Norton Pampus, Willich

Because of its high chemical resistance, PPSO$_2$ can be recommended for use as a reinforcing filler for *PTFE gaskets* in applications where high wear resistance and a low friction coefficient are both required. Unlike well-known fillers with a similar effect on frictional properties, such as glass fibres, graphite, PPS, PAR or PI, PPSO$_2$ does not impair the chemical resistance of the PTFE compounds [3].

PPSO$_2$ can also be used as a filler for fluorothermoplastics. This makes particular sense when mechanical characteristics such as hardness or yield stress have to be increased without lowering the chemical resistance of the compound. For example, a *pump housing for use in conveying aggressive media* is produced from PFA/PPSO$_2$ (title photo).

No mention has been made so far of the possibility of considerably improving *metallizability* by adding PPSO$_2$ to fluoroplastics or high-temperature resistant plastic (e.g. LCP, PSU, PES, PEEK, PAI). For example, by adding PPSO$_2$ it was possible to increase the adhesion of copper to fluoroplastics by a factor of 7 [3]. (100786)