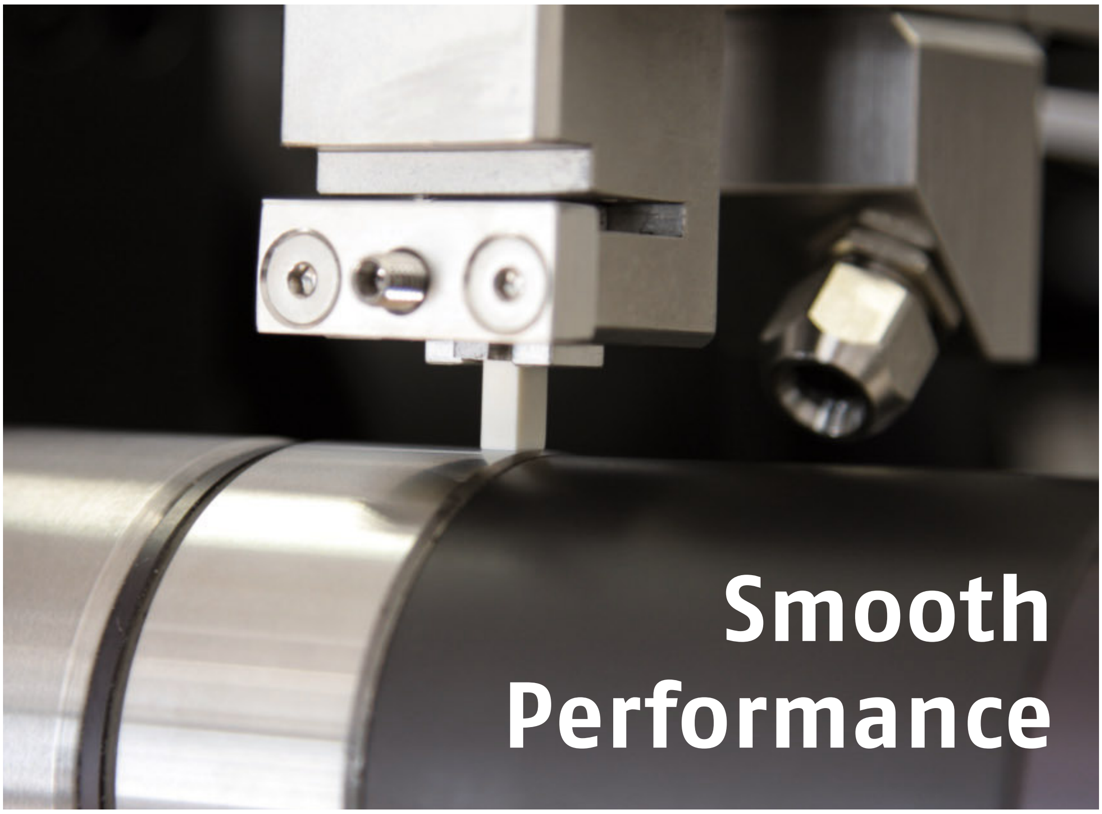

Smooth Performance

Block-on-Ring measurements of friction and wear of PEEK samples

(photo: NanoProfile)

A PEEK compound specially developed to have optimal tribological properties has good wear resistance whilst at the same time having extremely low friction. A range of tests was able to quantify this. Potential applications of these high-performance compounds can be found in metal replacement in highly loaded components such as gears.

MARKO GUTERL

Based on the high-performance plastic polyether ether ketone (PEEK) from Evonik Industries AG, Marl, Germany, Leis Polytechnik polymere Werkstoffe GmbH, Ramstein, Germany, has developed a compound for tribological applications.

The tribological properties of Triboforce PEEK C2301 were tested for the compounder by NanoProfile GmbH, Kaiserslautern, Germany, via comparative friction and wear measurements on a laboratory tribometer. Two commercial materials (WG 101 and WG 102) from Victrex Europa GmbH, Hofheim, Germany, were evaluated at the same time for reference. The tests were conducted using the block-on-ring configuration closely aligned with ASTM G 137. The test parameters were selected to deliver easily measurable wear after a sliding distance of just 21,600 m. The Atlas TT tester used (**Fig. 1**) can evaluate four samples simultaneously. As a result the throughput of such block-on-ring measurements is significantly higher than with the corresponding component testing. The time needed to achieve good statistical significance for the results is also much less than for component tests.

Test Conditions

In block-on-ring tests (**Title photo**) a rectangular sample is pressed onto a rotating counter body with a defined force. The influence of this force and the relative motion between the material sample and the counter body leads to the creation of a frictional force and progressive loss of material from the test piece. During the entire test both effects are precisely resolved against time and recorded.

The polymer samples needed for the frictional and wear measurements were produced by NanoProfile from tensile bars. With fiber filled polymers whose fiber orientation distribution shows a preferred direction the frictional and wear properties depend on the orientation between this and the sliding direc-

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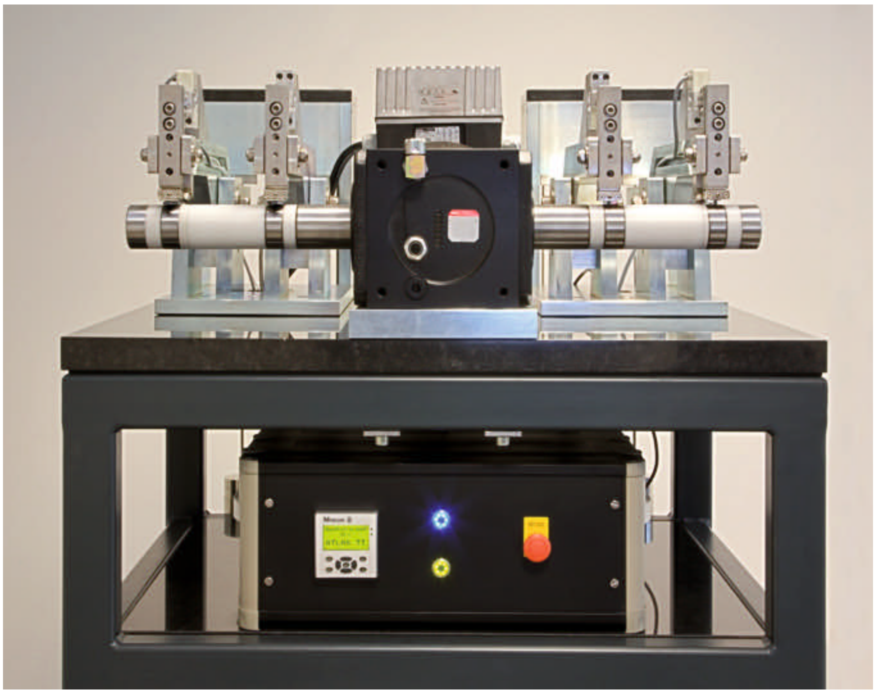

Fig. 1. The Atlas TT tester for determining friction and wear (photo: NanoProfile)

tion. Polymer pellets with randomly oriented short fibers can acquire a preferred direction during shaping processes such as injection molding or profile extrusion.

For example during injection molding of tensile bars from short fiber-reinforced polymers a high degree of orientation in the axial direction is often seen in the bar core. It is therefore possible to take samples with various fiber orientations from such tensile bars. For fiber-reinforced materials there are three different possible fiber orientations of the preferred fiber direction to the frictional surface and the sliding direction **(Fig. 2)**.

Since in most technical applications the fiber orientation is parallel the frictional and wear measurements were conducted with appropriate test pieces. In addition test pieces with normal fiber orientation were evaluated. In accordance with the requirements of DIN EN ISO 291 and ASTM D 618 all the samples were stored in a climate chamber for 40 h at 23 °C and 50 % rH before and after the measurements.

Measurements

Dry sliding wear measurements were conducted. **Table 1** summarizes the loading and environmental parameters of these measurements.

Since the Atlas TT tester has four independent measurement cells, four individual tests can be performed per run. In each test run the individual values for frictional force, wear and counter body temperature were statistically sampled for analysis according to the latest version of the relevant DIN standard (e.g. DIN 55303 or DIN 53804, Part 1). As part of this statistical analysis any possible outliers in the results for friction force, wear and counter body temperature were first assessed and where appropriate eliminated before the arithmetic mean $\bar{x}$ and the associated standard deviations s were calculated.

The average calculated from the sample was then used as an estimate for the position of the center of the population distribution. Analogously the standard deviation, as a measurement of the deviation of individual measurements from the median value, provides an estimation of the scatter of individual measurements within the population. However, this cannot be used as the exclusive measure of the certainty of the calculated median value.

This is instead given by the confidence interval, which is derived from the mean value $\bar{x}$ and the standard deviation s of the sample and the sample size n according to

$$\left[\bar{x}-\frac{s\cdot t_{\beta}(n)}{\sqrt{n}};\bar{x}+\frac{s\cdot t_{\beta}(n)}{\sqrt{n}}\right]$$

where $t_\beta(n)$ is the Student distribution for a sample size n and β is the significance level. The confidence interval is thus the range of values within which the actual value, that is the median value of the population, can be found with a probability of β. The significance level can for the most part be freely chosen by the experimenter, with 95 % being a very commonly used value in technical and scientific investigations. Therefore a significance level of 95 % was used throughout these investigations.

Parameter	Dry sliding
Contact pressure	5 MPa
Sliding speed	1.0 m/s
Sliding distance	21,600 m
Lubricant	none
Lubricant feed rate	n/a
Counter body	100Cr6: 60 HRc, Ra = 0.15 µm
Temperature control	Forced convection
Wear measurement	Time resolved
Friction force measurement	Time resolved
Recording of environmental conditions	Temperature, relative humidity

Table 1. Summary of the loading and environmental parameters for the sliding wear measurements (source: Leis Polytechnik)

Results

Table 2 summarizes the numerical results, that is the specific wear rates w_s, the linear wear rates w and the coefficients of kinetic friction μ, for the dry sliding tests. The values measured are given together with their confidence limits.

The measurement values obtained show that in respect of friction and wear there are in part clear differences between the three materials. With a normal fiber orientation Triboforce PEEK and WG 101 both have a specific wear rate of around $0.6\cdot10^{-6}$ mm³/Nm. With a value of $0.45\cdot10^{-6}$ mm³/Nm WG 102 is somewhat more wear resistant.

Differences between the three materials are seen in particular with a parallel fiber orientation. This fiber orientation is

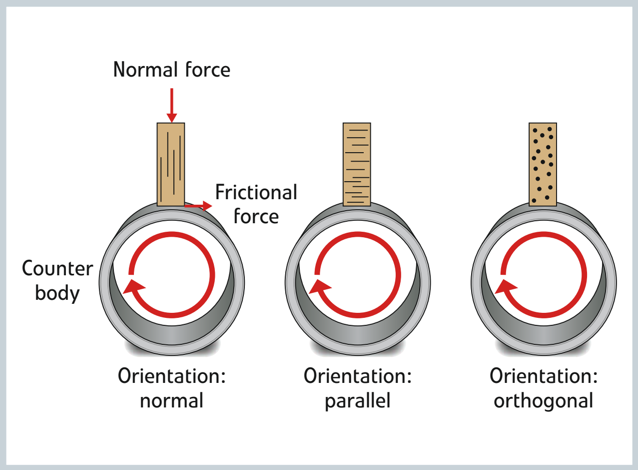

Fig. 2. There are three different possible fiber orientations between the reinforcing fibers, sliding direction and friction surface (source: NanoProfile)

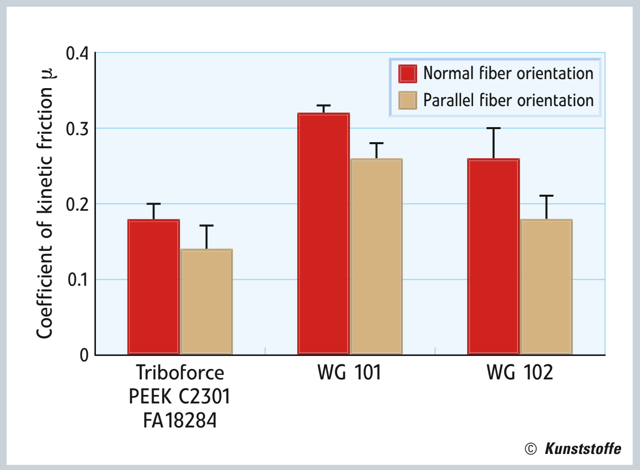

Fig. 3. Comparison of the coefficient of kinetic friction of the PEEK samples tested (source: Leis Polytechnik)

found predominantly in technical components. Accordingly friction and wear measurements should, where possible, be conducted with parallel fiber orientation. For the three materials investigated a different ranking was seen than with normal fiber orientation. In this case with $0.26 \cdot 10^{-6}$ mm^3/Nm Triboforce PEEK has the lowest specific wear and so is the most wear resistant. WG 102 occupies the middle ground with $0.31 \cdot 10^{-6}$ mm^3/Nm and with a value of $0.49 \cdot 10^{-6}$ mm^3/Nm WG 101 is the least wear resistant.

An additional relevant technical difference was found in respect of the coefficient of kinetic friction µ (**Fig. 3**). For Triboforce PEEK with normal fiber orientation this has a value of 0.18 and 0.14 for parallel orientation. In contrast the value for WG 101 at 0.26 with parallel fiber orientation is almost double this. WG 102 also has a comparatively low coefficient of kinetic friction at 0.18 for parallel fiber orientation.

Overall Triboforce PEEK due to its good wear resistance, extremely low friction and very short run-in behavior has the best tribological performance. Although WG 102 also has low friction it is not as wear resistant as Triboforce PEEK. In addition WG 102 has a pronounced run-in with substantially increased friction. The material with the poorest tribological performance was WG 101 with higher friction as well as a pronounced run-in with raised friction. ■

Material (batch)	Manufacturer	Fiber orientation	Specific wear rate w_s [10^{-6} mm^3/Nm]	Linear wear rate w [µm/h]	Coefficient of kinetic friction µ
Triboforce PEEK C2301 (FA 18284)	Leis Polytechnik GmbH	normal	0.6 ± 0.2	11 ± 4	0.18 ± 0.02
		parallel	0.26 ± 0.05	4.6 ± 0.9	0.14 ± 0.03
WG 101 (unknown)	Victrex plc	normal	0.62 ± 0.04	11.1 ± 0.7	0.32 ± 0.01
		parallel	0.49 ± 0.02	8.9 ± 0.3	0.26 ± 0.02
WG 102 (unknown)	Victrex plc	normal	0.45 ± 0.01	8.2 ± 0.2	0.26 ± 0.04
		parallel	0.35 ± 0.06	6 ± 1	0.18 ± 0.03

Table 2. Numerical results of the sliding wear measurements for all the PEEK compounds investigated (source: Leis Polytechnik)

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