Material selection for cleanroom application – Assessment of the particle emission

Material selection has a decisive influence on the functionality, cost-effectiveness and sustainability of a technical product. Material selection processes include a systematic analysis of requirements, properties and life cycle costs in order to achieve the optimum results for specific applications. The cleanliness of materials plays a decisive role in various branches of industry (see table 1), as it has a significant influence on the quality of products and processes. Applications from these sectors often take place in strictly regulated cleanrooms, the classification of which is governed by DIN EN ISO 14644. It specifies uniform criteria for the control of contamination. Guideline VDI 2083 Sheet 17 defines categories for the cleanroom suitability of materials and describes methods for testing them. [1]

Table 1: Industry specific overview of critical cleanroom related material parameters [1]

	Particles	Outgassing	ESD	Cleanability	Chemical resistance
Semiconductor Industry	++	++	++	+	+
Microsystems technology	++	+	++	+	+
Pharmaceutical industry	++	o	+	++	++
Biotechnology	+	+	o	++	++
Medical Technology	+	o	+	++	++
Photovoltaics	+	+	+	o	o
Food processing	+	+	o	++	++
++ required		+ recommended		o case by case decision	

The formation of particulate matter in our environment is largely due to the abrasion of materials.[2] This is one of the reasons why vehicles, for example, will have to comply with limit values for the abrasion of brakes and tires in order to meet the Euro 7 standard. Similarly, material abrasion resulting from the movement of surfaces against each other is a significant source of particles for cleanrooms. For these reasons, optimally designed variants of materials such as PVC, epoxy resins or polycarbonate are used when selecting construction materials for floors or walls, for example. However, production processes in cleanrooms generally require other materials and material combinations. The materials used must not only retain their functional properties after cleaning, exposure to radiation such as UV light or other process-related influences, but their outgassing properties and particle emissions must also not change.

Tribological tests examine friction and abrasion in systems of surfaces moving against each other. In classical tribology, tests are generally carried out in which high speeds and significant forces lead to macroscopically visible abrasion. These test scenarios are usually not representative for cleanroom applications, and they are particularly unsuitable for investigating fine particle abrasion. For this reason, the particle emission tribometer (PET) was developed in a collaboration between Materiales GmbH and the Competence Center for Tribology at Mannheim University of Applied Sciences.

The Particle Emission Tribometer (PET)

The PET is a tribological test bench that is operated in a clean room environment and is encapsulated from the surroundings. It can be used to carry out tribological material tests in ball-on-disc (ball on disk) or pin-on-disc (pin on disk) measurement geometry. Load and speeds are variably adjustable. Particles produced are fed directly from the friction gap into a Solair 3100 particle counter from Lighthouse using pre-cleaned compressed air and recorded there. Six particle categories are recorded: >0.3 µm, >0.5 µm, >1.0 µm, >3.0 µm, >5.0 µm and >10 µm. In addition to determining the particle emission, the course of the friction coefficients of the tested material pair is determined.

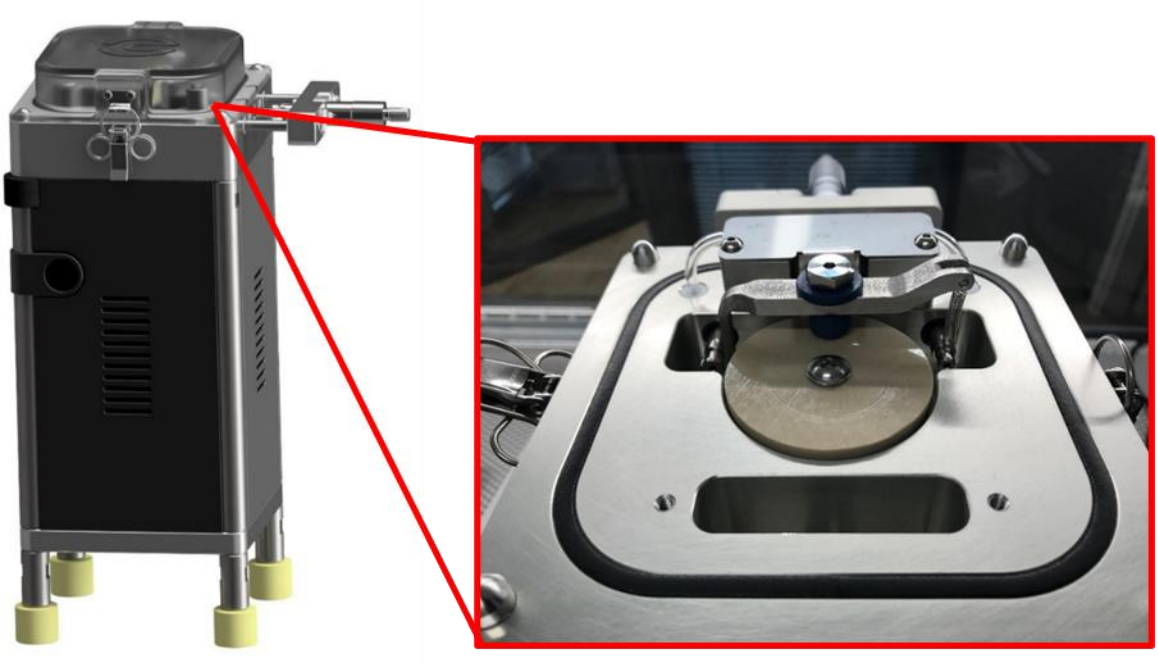

Figure 1: Side view of the PET and view of the open sample chamber with sample installed

A major advantage is the simplicity of the test setup, as test specimens are easy to prepare and a large number of tests can be carried out in a relatively short time. Theoretically, any combination of materials can be examined and findings can be gathered on a wide range of issues, such as

- Material preselection: Screening of different materials to reduce them to the best candidates
- Quality control: Evaluation of whether supplied surfaces are particle-free and whether the supplied surface qualities can sufficiently avoid particle emission
- Cleaning: Suitability or effectiveness of cleaning processes (media, ultrasound, etc.)
- Compatibility: Effect of external influences such as liquids, gases or radiation
- Material ageing
- Effect of coatings

The measurement

First, sample bodies are prepared to fit precisely so that they can later be inserted into the PET. Figure 2 shows three different plastics (polyoxymethylene (POM), polyetheretherketone (PEEK), polyamide (PA)) in the corresponding form. Also shown is a steel ball that is clamped in a pin lever and can be used to apply a defined force to the workpiece during a rotational movement. As a readily available ball material and common material, stainless steel or roller bearing steel is often used as a counterpart for plastics; in principle, all materials that can be manufactured as balls or pins can be used. Surfaces can be examined as supplied, alternatively defined states can be produced.

Figure 2: Material samples from POM, PEEK, PA prepared for assessment in PET

All work steps are carried out in a clean air workbench to minimize external contamination of the measuring system. Figure 3 shows the sequence of work steps for a measurement in the PET.

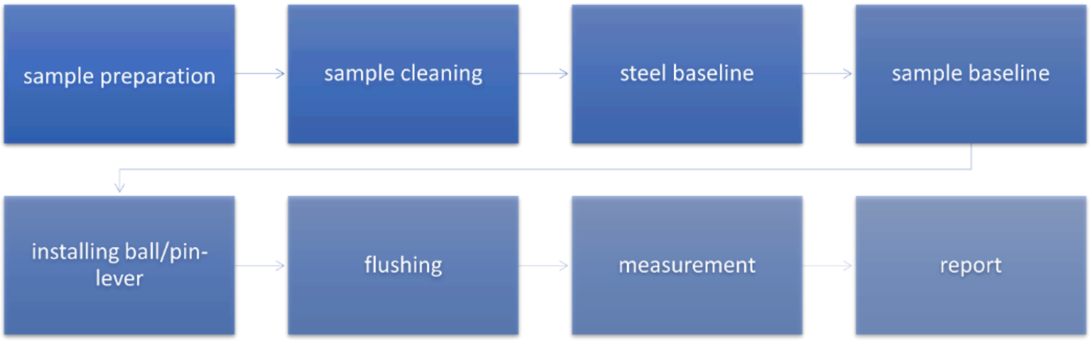

Figure 3: Fundamental procedure of a measurement with the PET

Before the samples are placed in the test bench, a background measurement of the system is carried out to determine the basic load of the test bench. The interior of the test stand is generally designed so that the basic particle load meets the requirements of an ISO class 3 cleanroom. In the next step, the basic particle load on the surface of the test specimen is usually determined using a surface probe. If the analysis with the surface probe shows that the contamination is within normal limits, the sample is installed in the system. This is followed by the actual measurements in the closed measuring system under a preset load of the ball (or pin) and speed of the disk.

The outcome

The results of an investigation with PET will be illustrated using tests with the polymers PA, PEEK and POM as examples. For this test, the polymers were brought to a roughness grade of N5 - N6 (Ra between 0.35 - 0.65 µm) for the best possible comparability after cutting to size. The counter body was a stainless steel ball (1.4125) of surface quality class G5. The measurement was carried out at 60 revolutions/minute and a force of 5 N. The time course of the formation of particles of size > 0.3 µm is shown in Figure 4; the measurement also provides identical information for all other five measured particle classes. To validate the results, three measurements are generally carried out for each material and load-velocity collective.

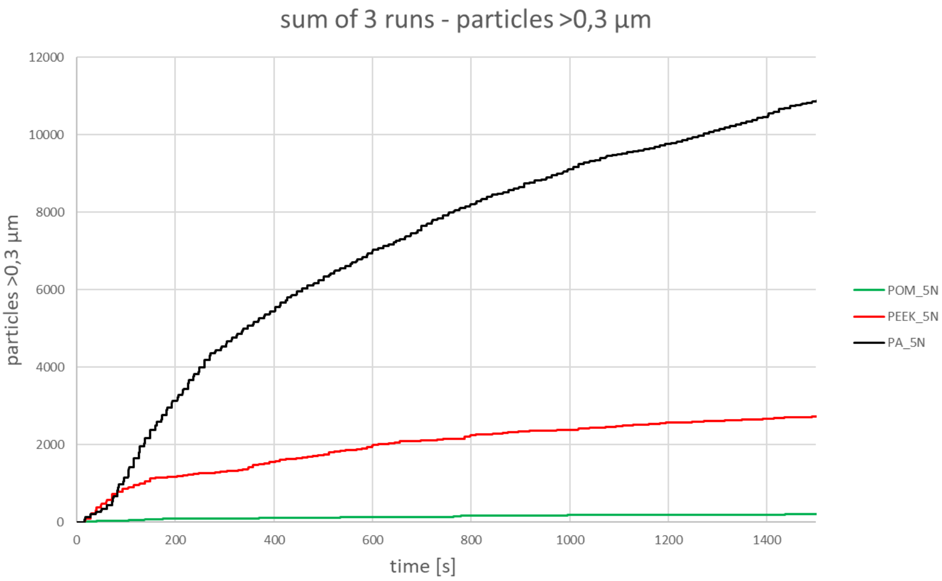

Figure 4: Particle sum of size > 0,3 µm in a measurement with POM (green, PEEK (red) and PA (black)

A very strong increase in particle formation can be seen for PA, as well as a continuous increase for PEEK. In the case of POM, particle formation remains constant at a low level over the duration of the experiment. On the basis of all the data, a classification based on ISO 14644-1 can be made for a given load-velocity collective by comparing the results with the limit values of the ISO air cleanliness classes (see Table 2 and Figure 5). [3] For this purpose, the particles formed over the measurement period are compared with the volume of air passed through. The evaluation is carried out relative to the quality of the compressed air in the test bench, which is determined as part of an empty measurement (baseline).

Table 2: Determination of an iso-class from the data at a test load of 5 N and a rotational speed of 60 rpm

	Particle sum						Iso category
	> 0.3 µm	> 0.5 µm	> 1.0 µm	> 3.0 µm	> 5.0 µm	> 10.0 µm	
PA	3648	1630	857	112	15	1	5,5
PEEK	928	542	286	36	3	0	5
POM	71	24	7	1	1	0	3,5

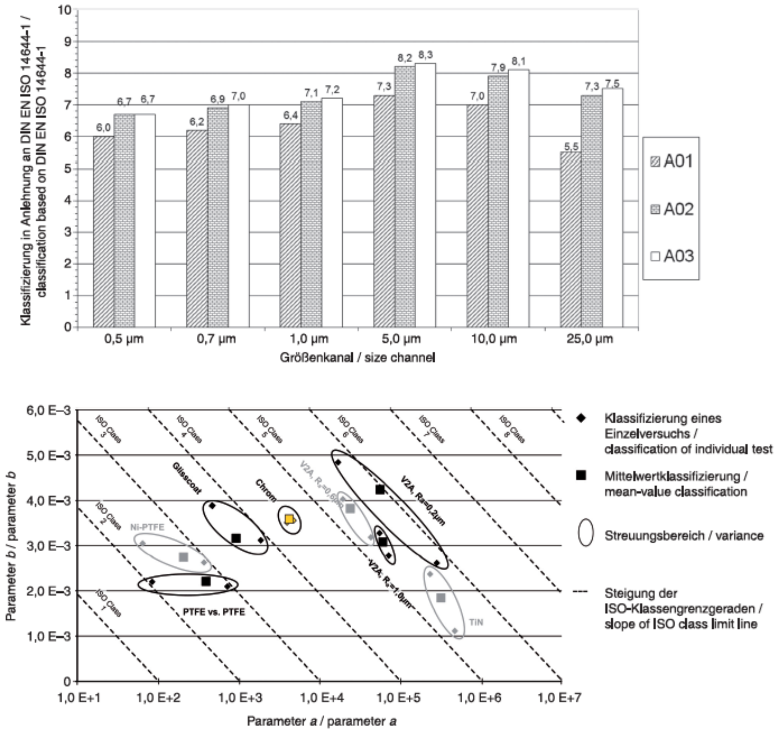

Figure 5: Classification of material pairs into corresponding ISO classes according to DIN EN ISO 14644 [2]

A more complete picture is obtained by including additional information. This includes the development of the coefficient of friction over time, shown in Figure 6. On the one hand, it can be seen that POM has significantly lower coefficients of friction than PEEK and PA under the given conditions - on the other hand, that the coefficients of friction for PEEK and PA are fairly constant after running-in, whereas they increase steadily for POM. As expected, low coefficients of friction therefore have an advantageous effect on particle emissions. The running-in process obviously only has a subordinate effect.

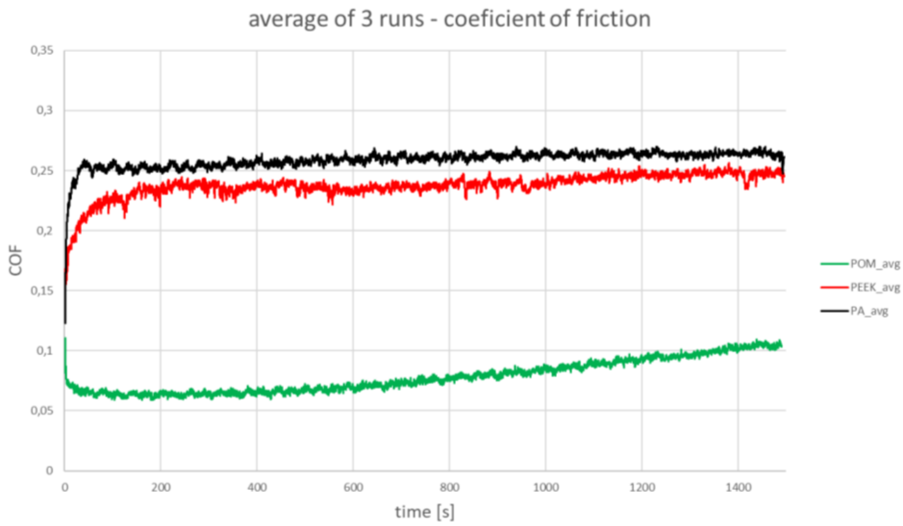

Figure 6: Timely progression of friction coefficient of the materials POM, PEEK and PA

Visual inspection of the running surfaces (see Figure 7) shows that the metal ball penetrated significantly deeper into the POM surface than was the case with the other two materials. The increasing coefficient of friction can therefore be explained by a continuous deepening of the running track. Apparently, however, this mainly resulted in a deformation of the surface and only little particle abrasion - or particles were pressed directly into the base material. In any case, the lowest particle emission occurred during the measurement with the greatest visual changes.

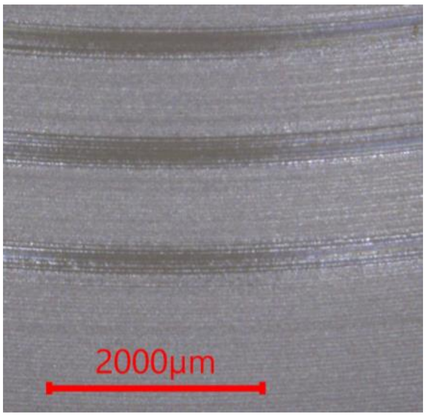

Figure 7: Visual inspection of running tracks after PET measurement

Summary

With the help of PET, it is therefore possible to gain valuable insights into the use of materials in a cleanroom environment in a short space of time. This not only speeds up the validation of materials and processes, but also makes it significantly cheaper compared to alternative procedures. The simplicity of the set-up also allows the uncomplicated investigation of unusual material combinations.

Please contact us for further information. You can reach us by email at **info@materiales.de** or by telephone on +49 40 / 572 567 35.

Literature

[1] VDI 2083 Blatt 17, Reinraumtechnik – Reinheitstauglichkeit von Werkstoffen, Verein Deutscher Ingenieure e.V., Düsseldorf, 2013.

[2] K. Li, K. Yu, Y. Zhang, H. Du, C. Sioutas und Q. Wang, „Unveiling the mechanism secret of abrasion emissions of particulate matter and microplastics", *Scientific Reports*, Nr. 14, 2024.

[3] ISO 14644-1: 2015, Reinräume und zugehörige Reinraumbereiche - Teil 1: Klassifizierung der Luftreinheit anhand der Partikelkonzentration, Beuth Verlag

