FRICTION AND WEAR TESTING CAN STEER THE DEVELOPMENT OF CERAMIC TRIBO MATERIALS

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SUMMARY
The development of materials for tribological applications requires test methods for the determination of friction and wear behaviour of these materials. One of many different test methods useful for this task is the "oscillating sliding test", working with a ball-on-disk configuration. This test is applicable on rather small specimens and can provide preliminary information on friction and wear behaviour of materials. Features of this test method and some benefits are described.

Keywords: friction, wear quantities, humidity, ball-on-disk, wear particles

1 INTRODUCTION
Ceramic materials often show beneficial tribological behaviour, but can be further improved by modification of composition and sintering process. The producer of "new" materials always needs a quick and sensitive tribological test method for the check of his efforts.

Tribo testing should always be performed with test parameters as close as possible to that of practical applications. If the application is not yet defined, various tribological test methods can be applied for "screening tests". Tribo tests with oscillating sliding motion, using a ball-on-flat arrangement, can provide easily preliminary information about friction and wear behaviour of the materials under development.

2 BASICS OF TRIBO TESTING
One of the objectives of tribo testing is the understanding of friction and wear processes in order to prevent damages caused by wear. Furthermore, friction is intended to be reduced or tailored for the reduction of energy losses or to grant the functionality of tribo systems. In order to reveal information about friction and wear behaviour of materials, two different goals have to be regarded:

- Analysis of damages in real machines, caused by wear or friction and the development of means against this damage,
- The development or improvement of materials with respect to friction and wear behaviour for general application.

In order to solve tribological problems one always has to keep in mind that friction and wear are NOT materials properties, but properties of a tribo system [1], consisting of at least two bodies in contact, depending on operational as well as on environmental conditions.

The solution of tribological problems in the field requires a tribological system analysis [2] and "model test" [3] with simple shaped (and therefore non expensive) specimens in a laboratory tribometer. The model tests have to use operational parameters as close as possible to that determined in the systems analysis.

Screening tests are performed in most cases in ambient air of room temperature. One of the most important environmental parameter in this type of tests is the relative humidity (R.H.) of the surrounding air [4]-[9].

3 OSCILLATING SLIDING TEST
3.1 General features
Tribo tests with oscillating sliding motion with ball-on-disk configuration, see Figure 1, can provide some beneficial features:

- only relatively small specimens are required, e.g. specimens for bending tests, Figure 2,
- many tests can be performed on one single specimen (Figure 3), linear wear can be measured on line with high resolution,
- friction and linear wear can be measured continuously with high accuracy without drift problems, Figure 4.
- volumetric wear can be quantified for both bodies in contact with high accuracy from the dimensions of the wear scars and additional profiles,
- wear particles can easily be collected, (Figure 2).

Figure 1: Ball-on-disk configuration in oscillating sliding tests
The size of the wear scars is of the order of mm², allowing tests on bending bars as used in fracture tests, Figure 2. On disks commonly used in tests with continuous sliding numerous tests are possible with oscillating sliding motion, Figure 3.

The linear wear $W_l$ can be measured by means of strain gauges, touching the ball and determining the change of distance from ball to disk. For a ball-on-disk the geometry the linear wear shows a square root curvature in the case of a constant volumetric wear rate.

3.2 Tribometer

A tribometer is used that is described in more detail in [x]. The typically used test geometry is ball-on-disk, as is shown in Figure 1. The tribometer is built in a chamber inside which the relative humidity can be varied between 2 % R.H. and 100 % R.H., but always kept constant during an individual test. The relevant test parameters stroke, frequency and load can be varied by nearly one order of magnitude each. Typical values of number of cycles are 100'000, in many cases stationary friction and wear behaviour is obtained in longer tests, lasting 13.9 hours ($10^6$ cycles with 20 Hz).

4 RESULTS

4.1 Influence of humidity

In tribological tests at room temperature, as performed often to get a first access to tribological performance of a material, the relative humidity can modify the results significantly. Figure 5 shows the wear scars on a SiC disk after tests in dry, normal and moist air. The size and the depth of the wear scar are the greatest in dry air, the coefficient of wear is nearly two orders of magnitude bigger in dry air compared with normal air.

The situation is quite different for tests with a ceramic composite ($\text{Si}_3\text{N}_4$-$\text{TiN}$), Figure 6. For this material the wear is the smallest in dry air.

Thus, variation of humidity in laboratory, as is common due to seasonal changes (summer $>50\ %$ R.H.; winter $<15\ %$ R.H.), can invert the ranking of materials with respect to wear rates! The evolution of repeatable and reproducible results will only be possible when the humidity effects are considered.
4.2 Ceramic tribo materials

Even though ceramics exhibit promising tribological performance, an improve of wear resistance is possible by changes of the composition or sintering process, leading to ceramic composites. Furthermore, the performance of ceramics might be improved by dispersion of fibres, platelets of (nano) particles in the matrix. Special attention was focussed on the composites in the system SiC-TiC-TiB$_2$ [11]-[17]. The wear rate could be reduced for unlubricated and water lubricated conditions. Another interesting system is the composition of Si$_3$N$_4$ and TiN, leading to an electrical conductivity that is sufficient for electro-erosive machining.

4.3 Mechanisms of wear

An important feature of simulation tests is the similarity of wear mechanisms in model test and damage in the real tribo system. The analysis of wear mechanisms can be done by various methods of surface analysis as SEM+EDX, TEM, Auger, ESCA, X-rays etc. A certain information can be revealed directly after the test from inspection of wear debris. In tests with 100Cr6/Si$_3$N$_4$ differences in the wear behaviour are visible in dry and in normal air, Figure 7.

While in normal air a smoothly curved linear wear evolution occurs (Figure 7), in dry air (left) the wear curve shows a significant change in wear rate after roughly 1 hour. The wear particles after the test in dry air are shown in Figure 8. This change can be correlated with a change of the wear mechanism. At the beginning of the test strong oxidative wear at the steel ball dominates, producing red-brown wear particles. After the "knee" in the linear wear curve tribo oxidation of the Ti phase of the ceramic dominates, producing creme coloured wear particles that accumulate at the rim of the wear scar.

While the coefficient of friction is nearly independent of the changes of mechanisms, in the case of SiC/SiC peaks in the friction curve, Figure 9, are nicely correlated to changes (dips) in the linear wear curve, indicating that tribo oxidation layers that are not stable in this system are removed from the tribo interface, always lifting the ball by a few µm.

Additional information can be provided by the evolution of electrical contact resistance $R$. This quantity however, is only of meaning for ceramics with a sufficient conductivity. As is shown in Figure 10, the peaks in the friction trace are correlated with peaks in the resistance. At each peak of $f$ a peak of $R$ indicates the increase of friction due to partial separation of the mating surfaces by non-conductive (oxidation) layers.
5 CONCLUSIONS

Oscillating sliding tests with ball-on-disk test configuration can provide preliminary information about friction and wear behaviour of tribio materials. The amount of volumetric wear can be determined at both bodies of the contact with high accuracy. Changes of the wear rate during the test can be determined by on-line measurement of the linear wear.

The influence of operational parameters can be studied, the sensitivity against effects of humidity can be revealed in tests at different values of R.H.

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7 REFERENCES


Figure 10: Evolution of coefficient of friction f, linear wear Wl and electrical contact resistance R in a test with 100Cr6 / SiSiC