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Brugger Test Redefined: Accelerated Wear Analysis of Sealing Materials

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The Brugger lubricant tester is a standardized, cost-effective method of investigating the behavior of lubricants under sliding loads within the mixed friction range. This measuring device is designed in accordance with DIN 51347. For this study, the device has been modified to enable elastomer testing. In the modified Brugger test, friction contact is initiated between a rotating steel cylinder and a test sample. The samples can either be prepared from sheet material or the wear can be tested directly on an O-ring. These modifications transform the device into a universal screening tool capable of quickly characterizing the wear behavior of materials, lubricants and surfaces in sealing technology.

1 Introduction

Dynamic seals are critical components in the field of fluid technology, and their service life depends significantly on tribological wear. Due to the growing demand for new materials, such as those subject to potential regulations on per- and polyfluoroalkyl substances (PFAS), there is a need for efficient testing methods that reduce the time and cost of testing components.

This paper describes how a Brugger lubricant tester, according to DIN 51347 [1], [2] was transformed into a universal screening tool for elastomers. Through specific mechanical modifications, thermography integration, and precise wear measurement, a method has been developed that allows for material characterization within minutes.

First, the measuring device in accordance with the DIN standard is presented, followed by an overview of the modifications made. Then, the procedure for testing sealing materials with the modified device is described.

1.1 Brugger Test according to DIN 51347

The Brugger lubricant tester, according to DIN 51347 [1], [2], is used to test lubricants under mixed conditions between two steel friction partners. In this method, a weighted steel cylinder lubricated with the oil to be tested is pressed onto a shaft. The two rotationally symmetric steel cylinders are aligned at 90° to each other. Initially, there is point contact. As the test ring wears down during the test, an elliptical contact surface develops. Figure 1 shows the schematic configuration of the Brugger testing device according to DIN 51347.

Parameters: The standard specifies a fixed sliding speed of 1.2 meters per second and a normal force of 400 newtons for a test duration of 30 seconds.

Analysis: During testing, an ellipse of wear is formed on the steel cylinder. The area of the ellipse is then analyzed to characterize the resulting wear and, thus, the performance of the lubricant.

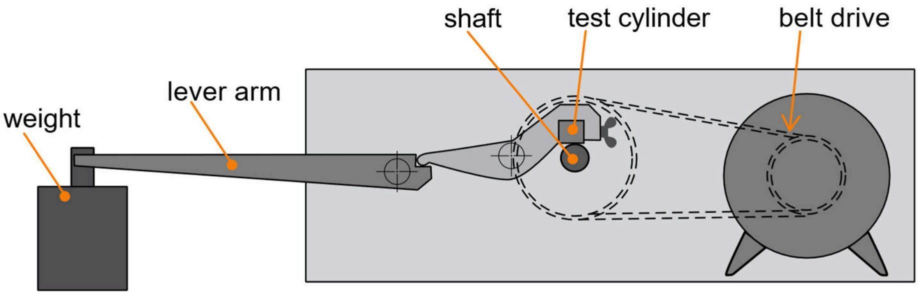

Figure 1: Setup of the Brugger lubricant tester based on DIN 51347

Limitation: Since the samples are secured with only one screw, the design is not suitable for testing elastomer samples. Additionally, the device does not support variable speeds and can only be operated using an on/off switch.

These limitations were overcome by applying the modifications described in the following section.

1.2 The Modified Experimental Setup

A Brugger lubricant tester according to DIN 51347 was modified to enable testing of materials used in sealing technology. Figure 2 shows the final configuration of the modified Brugger measuring device. In this configuration, an adapter for clamping flat samples is mounted. This adapter can remain in place, and only the flat sample needs to be replaced for each test.

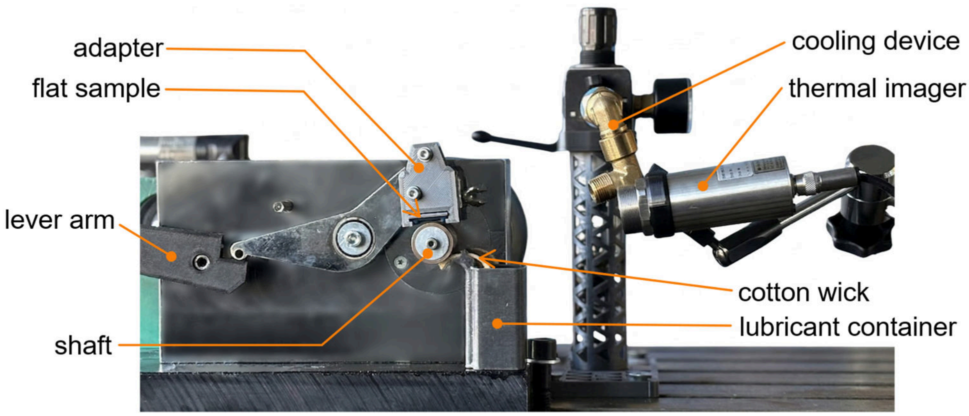

Figure 2: Final Configuration of the modified measuring device

Similar to the setup according to DIN 51347, a weight can be attached to the lever arm to apply a normal force between the sample and the shaft. The shaft is the same one used in the original Brugger measuring device.

The measuring device is equipped with a cooling device that uses compressed air to cool down the shaft after an experiment. The thermal imager measures temperatures within its field of view. These temperatures are then evaluated to determine the maximum temperature in the contact area.

A lubricant container with a cotton wick allows lubricated testing. The flat cotton wick draws oil from the container to the shaft. The 12-mm-wide wick has the same width as the shaft to ensure an even distribution of lubricating oil across its entire surface.

1.2.1 Drive and Control System

The standard motor has been replaced with a variable-speed drive, enabling variable sliding speeds and reversible rotation directions. A LabVIEW interface is used to set the test duration and rotational speed.

1.2.2 Sample Geometries

Sheet material is typically used as a test material for production quality control. For example, 2-mm-thick sheet material is used to make S2 shoulder bars for tensile tests according to DIN 53504 [3]. Therefore, a flat sample geometry made from sheet material was designed.

For seal manufacturers who already produce sheet material, flat samples are an optimal test geometry that can be produced easily. For end users without access to the sheet material, O-rings measuring 20.22 mm x 3.53 mm were tested as an alternative. Both sample geometries are shown in Figure 3.

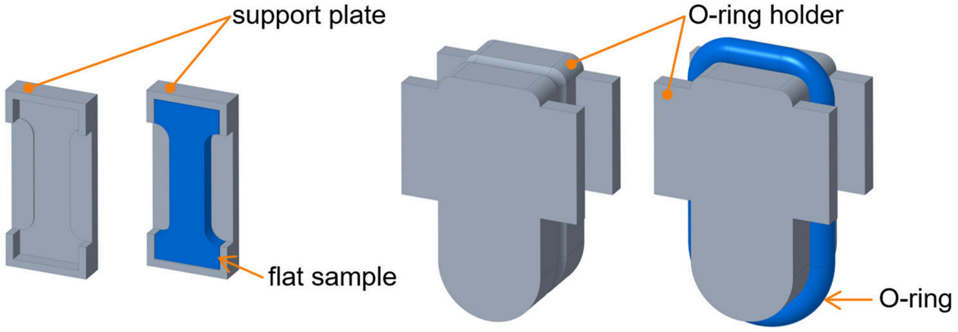

Figure 3: Support plate for flat samples (left) and O-ring holder for O-rings (right)

The flat samples are first glued to a support plate before being mounted into the adapter on the Brugger measuring device. The O-rings are installed in the groove of an O-ring holder, which is fixed directly onto the measuring device.

1.2.3 Thermotribological Modifications

Since the wear behavior of elastomers is significantly influenced by the temperature at the contact area, the measurement device was equipped with a thermal imager and a compressed air cooling device.

The Optris Xi 400 stationary thermal imager measures the temperature at the contact area from a distance of about 10 cm, Figure 2. Thus, the camera measures the temperature from the outside and cannot measure the exact temperature between the contact partners.

Figure 4 shows four thermal images taken during a test with flat samples made of fluorocarbon rubber (FKM) and a circumferential speed of 1.96 m/s. The settings used for the infrared temperature measurements were an emissivity of ε = 0.95 and a transmittance of 100 %. The image on the left was taken five seconds after the start of the test. The other images were taken 10, 20 and 40 seconds after the test began. The highest temperature is shown in white and the lowest in dark blue.

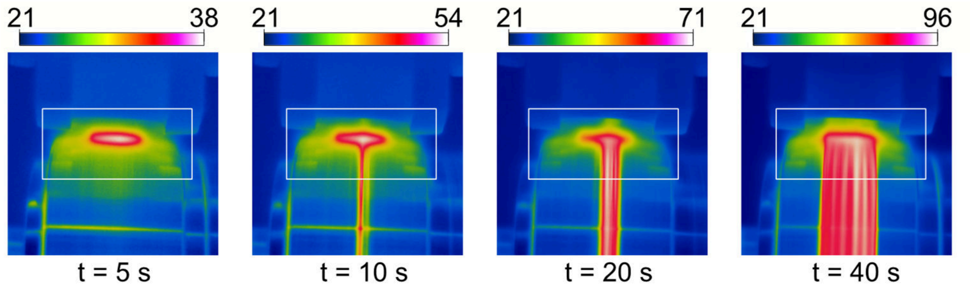

Figure 4: Recordings from the thermal imager with the analysis area and the minimum and maximum temperatures given in °C

A MATLAB script was used to analyze the thermal images in combination with the additionally stored raw data, in order to plot the temperature over time. For each test run, an analysis area was defined and is shown in Figure 4 as a white rectangle within each of the four thermal imager recordings. The maximum temperature value recorded within this rectangular analysis area was then plotted over time.

Additionally, a compressed air cooling device was integrated into the test setup to prevent overheating of the contact area during test runs and to ensure consistent thermal conditions. As shown in Figure 2, the air nozzle is positioned so that a controlled airflow is directed onto the contact area. This dissipates frictional heat, stabilizing temperatures and preventing premature failure of the samples due to thermal damage.

1.3 Testing Procedure

The testing procedure for flat samples involved three steps: preparing the flat samples, conducting the experiments, and measuring the samples' wear.

1.3.1 Sample Preparation

Three different 2 mm sheet materials have been tested. The material data of these fluorocarbon rubbers (FKM) are shown in Table 1.

Table 1: Material data flat samples

ID	Density [g/cm3]	Elongation at break [%]	Hardness [Shore A]	Tensile strength [MPa]
FKM_1	1.85	190	75	13.5
FKM_2	2.05	220	75	14.5
FKM_3	2.03	220	75	14.8

The FKM_1 sheet material was produced by one manufacturer. The FKM_2 and FKM_3 materials were produced by a different manufacturer. All three materials have a Shore A hardness of 75. FKM_2 and FKM_3 are nearly identical in their other properties.

The flat sample was laser-cut from sheet material and then glued to a support plate. The support plate is then clamped onto the adapter, which is mounted on the Brugger device, Figure 2.

1.3.2 Experiment

First, the flat samples were mounted on the Brugger measuring device. Then, the test parameters (rotational shaft speed and test duration) were set in the software, and the test was started. After the defined test duration, the shaft stopped. Lastly, the flat sample was removed and measured using the IMA-Sealscanner [4] to determine the wear depth.

The temperature at the contact area was recorded with the thermal imager during all tests. Since the shaft heats up during the tests, it was cooled down with compressed air between test runs to ensure the same starting temperature for all tests.

New samples were used for each test run; the flat samples that had already been tested were not reused in any further tests.

1.3.3 Wear Measurement

After testing, the wear depth was measured using the IMA-Sealscanner. The samples were positioned centrally beneath the 2D laser of the optical measuring device for this measurement, as shown in Figure 5. Using laser line triangulation, the IMA-Sealscanner then measures the height profile over the 2D laser. Figure 6 shows the height profile of a measurement taken on a flat sample.

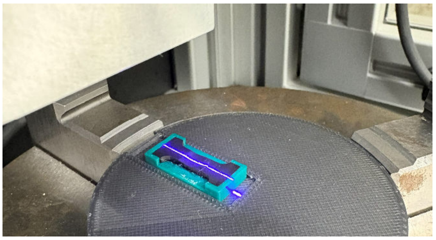

Figure 5: Flat sample, IMA-Sealscanner

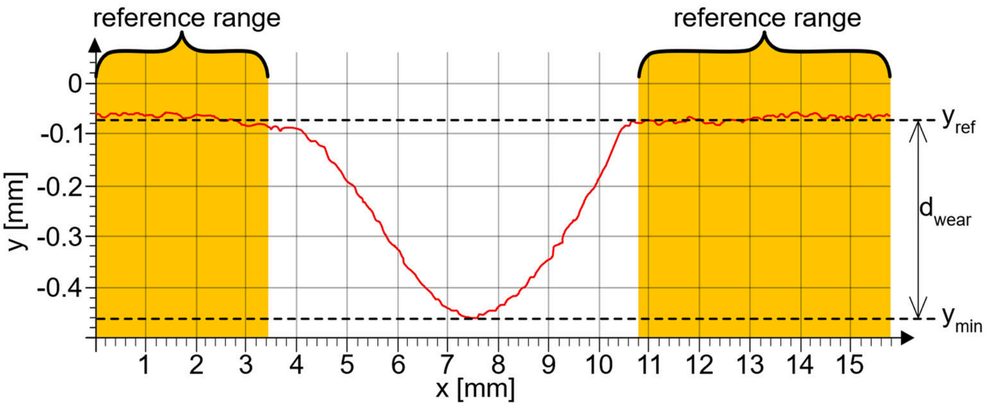

Figure 6: Measurement of a flat sample with the IMA-Sealscanner (dry test, 160 m)

To determine the wear depth, the two reference ranges that represent the height profile of the unworn sample must first be defined. The average of these two height profiles yields the value y_{ref}. The wear depth d_{wear} is found by subtracting the reference height $|y_{ref}|$ from the lowest point of the measurement $|y_{min}|$.

2 Results Flat-Samples

The following section presents the wear depths measured after the tests as well as the temperatures measured during the tests, and compares these for the materials listed in Table 1. Additionally, the results are compared for three contact conditions:

- **Dry**: no lubrication, no cooling during the tests.
- **Air-cooled**: Compressed air is directed onto the contact area during the test.
- **Lubricated**: The mineral oil FVA1 was used to lubricate the shaft surface, as described in Chapter 1.2.3. This paraffin-based, solvent-refined oil is recommended by the Research Association for Drive Technology (FVA) as a reference oil for experimental studies in research projects [5].

All tests were performed at a circumferential speed of 1.96 m/s with a 200 g weight attached to the lever arm. This resulted in a normal force of 25 N.

2.1 Wear Depths – Dry Contact

Figure 7 shows the measured wear depths over the sliding distance for the three tested FKM materials. Three tests were conducted for each data point, leading to a total of 27 tests per material. The error bars show the standard deviation for each of the three test runs.

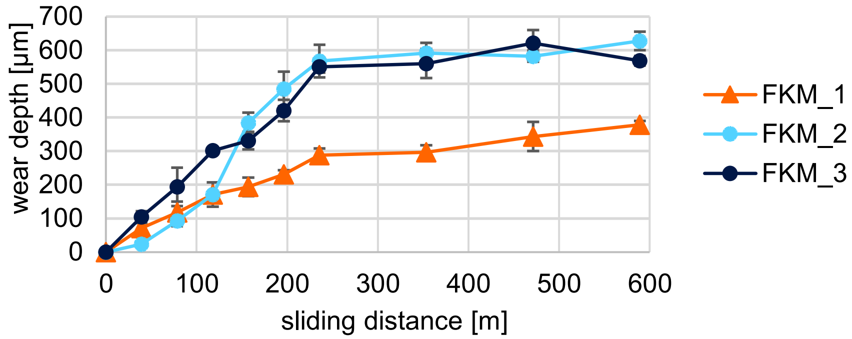

Figure 7: Wear depth on flat samples after dry test runs

As expected, the wear behavior of FKM_2 and FKM_3 is very similar, given their similar material properties and the fact that they are from the same manufacturer. The wear behavior of the FKM_1 material differs from that of the FKM_2 and FKM_3 materials. Thus, the wear behavior of the three materials can be classified using the modified Brugger test.

The maximum standard deviation is 43 µm for FKM_1 (470 m), 50 µm for FKM_2 (196 m), and 46 µm for FKM_3 (79 m). Therefore, the tests are considered reproducible.

2.2 Wear Depths – Lubricated Contact

Figure 8 shows the measurement of a flat sample made of FKM_1 after a five-minute test (588 m) using FVA-1 reference oil [5] as a lubricant. As explained in Section 1.3.3, first, the average value of the two reference ranges was determined, after which the difference to the lowest measurement point between these ranges was calculated. For the measurement shown, this results in a wear depth of 19 µm.

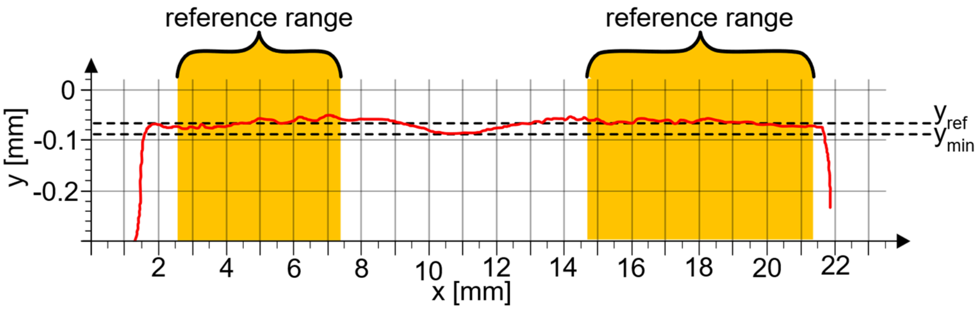

Figure 8: Measurement of a flat sample with the IMA-Sealscanner (lubricated test, 600 m)

Since this very small wear depth could have been caused by plastic deformation, additional tests were performed with the shaft standing still. Similar to the dynamic tests, FKM flat samples were mounted on the Brugger measuring device and a 200 g weight was attached to the lever arm. Rather than rotating at 1,500 rpm, the shaft remained still. After five minutes, the samples were removed, and the wear depth was measured using the IMA-Sealscanner.

Figure 9 shows the results of the lubricated tests. Three samples of each material were tested without movement to obtain a reference value for plastic deformation. Then, three samples of each material were tested for five minutes, and three for one hour. The error bars show the standard deviation of the three samples.

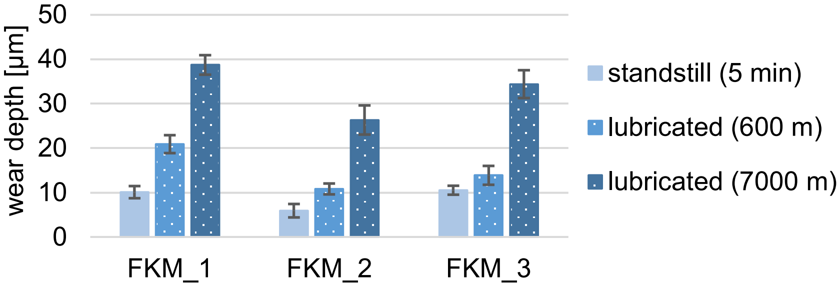

Figure 9: wear depth on flat samples after lubricated test runs

Comparing the wear depths after five minutes of standstill and under lubricated conditions after 600 meters, which also corresponds to a five-minute test run, highlights the difficulty of evaluating such small wear depths. For the tests with FKM_3, the average wear depth after the dynamic tests was only 30 % greater than the wear depths measured after five minutes of standstill.

However, compared to the wear depths after the tests without lubrication, Figure 7, the wear depths after the lubricated tests are significantly lower: The average wear depth after 7,000 meters under lubricated conditions was only 13 % (FKM_1), 4.6 % (FKM_2) and 5.6 % (FKM_3) of the average depth after a 400-meter test under dry conditions. The small indentations caused by plastic deformation are even smaller and therefore considered negligible in the dry tests. For lubricated tests, however, it is important to ensure that the sliding distance is long enough to yield reliable, measurable wear. Otherwise, slight plastic deformation could be misinterpreted as wear.

2.3 Contact Temperatures and Comparison

Measuring the temperature in the contact area during test runs revealed significant differences between dry and lubricated tests, as shown in Figure 10. While the temperatures in dry tests rise rapidly to as high as 160 °C, the temperatures in lubricated tests remain below 40 °C, even after 7 km.

Using compressed air for cooling only slightly slows the rise to high temperatures. After a while, the measured temperatures reach values similar to those in dry tests.

The compressed air cooling system is designed to dissipate frictional heat from the shaft's surface through convection. However, given the high temperatures measured, Figure 10, it appears that more frictional heat is generated than can be dissipated by air cooling, indicating that the cooling effect is insufficient.

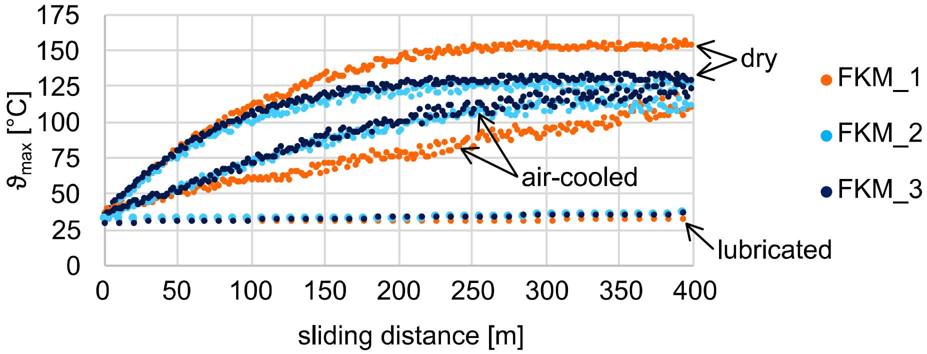

Figure 10: Contact temperature during dry, air-cooled and lubricated test runs

Figure 11 compares the wear depths measured after dry, lubricated, and air-cooled tests. Three tests were conducted for each condition; the error bars indicate the standard deviation. The wear depths after 7 km under lubricated conditions are the same as in Figure 9. After a sliding distance of 350 m, the temperatures measured during the air-cooled tests with FKM_2 and FKM_3 were almost as high as those in the dry tests, Figure 10. Likewise, the measured wear depth decreased only slightly (24 % for FKM_2 and 17 % for FKM_3) due to air cooling.

The FKM_1 material showed a different behavior: The temperatures measured after 350 m were still approximately 50 °C lower than in the dry tests, and the measured wear depth was 70 % lower. Therefore, the air cooling had a much greater effect on the FKM_1 material than on the other two materials.

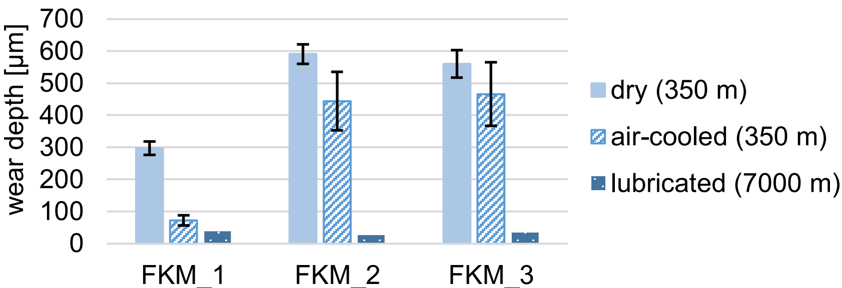

Figure 11: Wear depths on flat samples after dry, lubricated and air-cooled test runs

It is also notable that the maximum temperatures measured in the dry tests using the FKM_1 flat samples settled at a level 30 °C higher than the temperatures recorded in the tests with the FKM_2 and FKM_3 flat samples. Nevertheless, lower wear depths were measured for the FKM_1 material. There could be several reasons for that:

- Wear particles as a lubricant: The wear particles from the FKM_2 and FKM_3 materials serve as lubrication, lowering the coefficient of friction and thus reducing frictional heat.
- Cross-linking and filling materials: The cross-linking density and the type of filler used affect wear behavior and temperature development.
- Thermal conductivity: The lower the thermal conductivity of the FKM_1 material, the more heat accumulates in the contact area, resulting in a higher maximum temperature. The higher the thermal conductivity of the other materials, the faster they dissipate the heat, keeping the maximum temperature low.

Without knowing the cross-linking density and filler content of the materials, it is impossible to assess the underlying causes reliably. However, the findings from the wear tests can help identify such patterns of behavior, allowing for a general evaluation of the materials, even if the specific causes cannot always be determined without further knowledge of the materials.

3 Results O-rings

To verify that the modified Brugger test is applicable to characterizing the wear behavior of materials on an O-ring geometry, O-rings measuring 20.22 × 3.53 mm and made from the following materials were tested:

- **FKM70**: Fluorocarbon rubber material (FKM) with a Shore A hardness of 70.
- **FKM80**: Fluorocarbon rubber material (FKM) with a Shore A hardness of 80.
- **EPDM**: Ethylene Propylene Diene Monomer material (EPDM) with a Shore A hardness of 70.

All tests were performed at a circumferential speed of 2.6 m/s with a 200 g weight attached to the lever arm. This resulted in a normal force of 23 N.

Figure 12 (left) shows a microscopic image of a wear ellipse on an O-ring made of FKM70. After each test, the minor axis b and major axis a of the wear ellipse were measured and used to calculate the ellipse's area. This procedure is comparable to that in DIN 51347, in which the longitudinal and transverse axes of wear ellipses are determined to characterize wear on steel specimens.

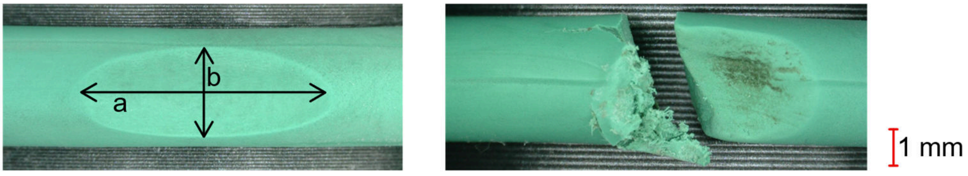

Figure 12: Wear ellipse on an O-ring (left) and torn O-ring (right)

O-rings made from each material were tested under dry, air-cooled, and lubricated conditions. Figure 13 shows the measured areas of the wear ellipses. Each test was repeated five times; the error bars show the standard deviation.

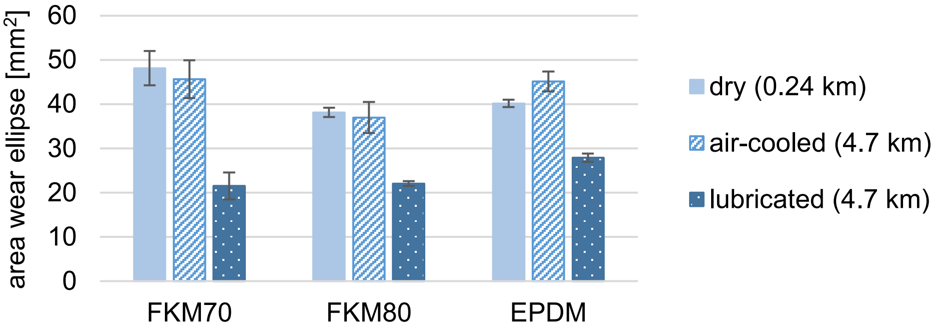

Figure 13: Area wear ellipse

Testing at a sliding distance of 4.7 km or longer was impossible without air cooling or lubrication, as the O-rings ruptured, Figure 12 (right). However, air cooling during the tests made it possible to test such distances, though the measured wear remained high afterwards. Significantly reducing wear was only achieved by lubricating with FVA-1 reference oil. This confirms the assumption made based on tests with flat samples that the cooling capacity of air cooling is insufficient compared to the frictional heat generated.

Furthermore, the measured wear areas in Figure 13 indicate that the three materials tested can be characterized in terms of their wear behavior using the modified Brugger test. Under dry conditions, FKM70 showed greater wear than FKM80 and EPDM. Comparing the dry and lubricated test results reveals that FKM70 exhibits the greatest reduction in wear area due to lubrication. Additionally, both FKM materials showed less wear than the EPDM material when lubricated.

One possible reason for the more significant wear on the EPDM O-rings could be that EPDM is generally incompatible with mineral oils, such as the FVA1 reference oil. However, given the short test duration

of just 30 minutes, it was expected that the thin lubricant layer on the shaft would significantly affect the material.

Measuring the area of the wear ellipse, similarly to the procedure in DIN 51347, is a quick and efficient method for characterizing and comparing the wear behavior of O-ring materials. However, the area of the wear ellipse does not provide information about the wear volume. Furthermore, it should be noted that the wear area increases at varying rates. Initially, the area of the wear ellipse increases rapidly with increasing wear depth. Once the wear depth approaches the center of the O-ring ($d_{wear} \approx r_{o\text{-}ring}$), the minor axes b of the wear ellipse stops increasing. Wear ellipses of such large dimensions were not evaluated.

4 Summary and Conclusion

A Brugger lubricant tester according to DIN 51347 was modified to enable elastomer testing. The test results have shown that the modified Brugger test is a universal method for quickly characterizing the wear behavior of materials and lubricants used in sealing technology. Within a few minutes, reproducible wear information about elastomers can be acquired.

Wear tests were performed on 2-mm-thick sheet material in the form of flat samples, as well as on O-rings. The tested materials could be characterized based on their wear behavior, both in the O-rings and in the flat samples.

Although all of the sheet materials tested were of the same FKM type, their wear behavior could be clearly differentiated after test periods of just two to five minutes in dry conditions. In the case of the O-rings, differences in the wear behavior of two different FKM materials and one EPDM material could be identified after one to 30 minutes, depending on the lubrication conditions.

The IMA-Sealscanner was used to reliably measure the wear depth on the flat samples, especially after test runs under dry conditions that resulted in significant wear. Tests with lubrication resulted in much smaller wear depths, which required much longer test distances to achieve measurable wear using the IMA-Sealscanner. In cases where wear depths are very small, it has been shown that care must be taken to ensure that plastic deformation of the material is not mistakenly measured and interpreted as wear.

To characterize the wear on O-rings, the area of the wear ellipse was measured using a digital microscope, similarly to the procedure in DIN 51347.

Initially, the contact area between the O-ring or flat sample and the shaft is small. Due to wear, this contact area quickly increases and continues to grow. Consequently, the surface pressure between the sample and the shaft decreases during testing. This reflects the situation in a sealing system, such as with rotary shaft seals. As the sealing edge of a rotary shaft seal wears, the contact area between the sealing edge and the shaft increases, causing the surface pressure to decrease. This makes the modified Brugger measuring device an ideal tool for testing the wear behavior of materials used in sealing technology.

Although cooling with compressed air slowed down the temperature increase, temperatures still reached the same levels as in tests without cooling. Therefore, the air cooling used is insufficient to dissipate the generated frictional heat. Nevertheless, cooling the shaft with compressed air between tests ensures consistent starting conditions, which is why the cooling device remains essential.

5 Acknowledgements

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6 Nomenclature

Variable	*Description*	*Unit*
a	Major axis of an ellipse	[µm]
b	Minor axis of an ellipse	[µm]
d_{wear}	Wear depth	[µm]
ε	Emissivity	[-]
r_{oring}	Radius of an O-ring	[mm]
ϑ	Temperature	[°C]
y_{min}	Lowest measurement point	[mm]
y_{ref}	Average of all measurement points in the reference range	[mm]

7 References

[1] German Institute for Standardization*: DIN 51347-1*, Beuth Verlag GmbH, Berlin, 2000.

[2] German Institute for Standardization*: DIN 51347-2*, Beuth Verlag GmbH, Berlin, 2000.

[3] German Institute for Standardization*: DIN 53504*, Beuth Verlag GmbH, Berlin, 2017.

[4] University of Stuttgart - Institute of Machine Components: *IMA-TechSheet #102050 V2*, available at https://www.ima.uni-stuttgart.de/dokumente/forschung/dichtungstechnik/einrichtungen/en/102050en.pdf, accessed on April 9, 2026.

[5] Siewerin, B. et al.: *Referenzöle 2019*, Final report on research project No. 852 I, Research Association for Drive Technology (Forschungsvereinigung Antriebstechnik e.V., FVA), Issue 1470, 2022.

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