EXPERT KNOWLEDGE
FAILURE ANALYSIS
OF ELASTOMER COMPONENTS

An offer of

O RING PRÜFLABOR RICHTER

TESTING CONSULTING DEVELOPING

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Excessive Abrasion
The Elastomer Seal: A Soft Partner in a Hard Environment

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1. Classification and Frequency of the Damage Pattern

Out of the four main damage mechanisms, excessive abrasion is classified in the third main group:

1. Mediums
2. Temperature / Aging
► **3. Mechanical / Physical Effects**
4. Manufacturing Defects

The third main group can be divided into three subgroups: assembly errors, incorrect installation space and physical overloading due to operating conditions. Excessive abrasion belongs to the last subgroup, which also includes damages such as gap extrusion, explosive decompression or overheating, air in the oil or seal overflow (blow-by effect).

This defect pattern caused failures on approx. 2.5% of over 2000 elastomer seals tested in the O-Ring Prüflabor Richter.

2. Technical Background Knowledge on the Damage Pattern

In literature, the damage pattern "excessive abrasion" is also referred to as "excessive abrasion wear"[1] or "abrasion wear."[2]
This type of damage mainly occurs with moving seals and can have many different causes. In many cases with this type of damage, there is usually not only one cause, but a combination of causes (e.g. too rough counterface in combination with poor lubrication and unsuitable seals). Generally, the environment must always be taken into account in a seal damage analysis, but this applies particularly to the damage pattern of abrasion, since very often it is not the seal but the sliding mating component and/or the contact medium that causes the damage.
Abrasion is caused by friction and is linked to one another as follows:

- "The friction is proportional to the surface pressure.
- The abrasion is proportional to the friction.
- The heating of the seal is proportional to the friction"[3]

2.1 Unsuitable or Damaged Mating Surface

It is ancient knowledge that harder materials scratch softer ones. The mineralogist Friedrich Mohs made this knowledge his own when he developed the Mohs scale of hardness. It consists of ten minerals in ascending hardness (1 = talc to 10 = diamond). A mineral can always be scratched by another mineral which has a higher number than itself.
Generally, rubber seals are many times softer than the components in which they are mounted and are therefore susceptible to damage and abrasion. Particular care must be taken with moving seals to ensure that the mating surface is as smooth as possible and has no sharp edges or transitions. Often "chrome plating after grinding cannot replace polishing".[4]
Individual depressions, e.g. caused by damage, are also very critical. For one, they can have sharp edges and for another, soft rubber material can be pressed into a recess by pressure. When the seal is moved, this material will then be sheared off.

2.2 Hydroabrasion (= Abrasive Solid Particles Dissolved in Mediums)

This defect pattern is caused by the same circumstance as above, namely that harder materials scratch or grind softer ones. If a mating surface has only one specific damage spot, it can usually be localized on a seal. In contrast, abrasive solid particles (e.g. metal particles) which are "dissolved" in mediums usually cause grooves in the sealing surfaces, which are

[1] Vgl. SCHRADER, Klaus: Hydaulik-Dichtungen Teil II: Schadensbilder, -ursachen, -vermeidung in o+p Ölhydaulik und Pneumatik, Heft 5, Band 26, 1982, S. 357
[2] Translated from PARKER Hannifin GmbH (Hrsg.): Prädifa Dichtungshandbuch, August 1999, P. 101
[3] Translated from PARKER Hannifin GmbH (Hrsg.): O-Ring Handbuch, November 2005, P. 172
[4] Translated from PARKER Hannifin GmbH (Hrsg.): Prädifa Dichtungshandbuch, August 1999, P. 101

washed out and enlarged by erosion[5]. Erosion marks can easily be found under the microscope. Solid particles can also be seen under a well-lit microscope, as long as they have not been rinsed out. REM EDX can also be used to determine the material of the particle in case of doubt, which often clarifies its origin.
Problems due to grooves are more common in hydraulics. "Particles in the sealing and guide gaps grind longitudinal marks into the surfaces of the rods and cylinders. The sealing performance does not deteriorate as long as these marks are not deeper than some µm (...). However, the hydraulic fluid flows through deeper axial grooves at high pressure at high speed. This results in erosive wear (...). In order to minimize such damage, the rod and cylinder surfaces should be as hard as possible".[6]

2.3 Dry Running Conditions or Inadequate Lubrication

When machines are started up for the first time, dynamically used seals usually undergo a short dry run until they are supplied with lubricant. According to investigations by MÜLLER and NAU "this did not, however, lead to statistically detectable disadvantages with regard to dynamic tightness in later operation".[7] When dry rotary shaft seals start up for the first time, the contact zone is merely widened, but this usually has no negative consequences for the subsequent function of the seal.
However, if lubrication fails to occur during operation, the seal can already be so severely abraded after a few minutes (depending on the dynamic load) that it fails completely.
Due to dry running conditions or inadequate lubrication, the seal also experiences an increased temperature in the contact area. "Wear is usually associated with the detachment of rubber particles, which means chain breakage, so that the temperature also plays an important role. Higher temperatures generally result in higher elasticity of the products, but also in chain degradation to an even greater extent."[8]

2.4 Constructional Defects (Faulty Design)

A common mistake is an imprecisely defined surface condition of the mating surfaces. Not only the degree of roughness should be specified, but also the machining process and the topology of the surfaces.
Too little pre-compression of the seal (e.g. missing consideration of the diameter tolerance) can lead to flow erosion due to dynamic gap or pressure changes. The danger is particularly great with O-rings, as the preload of O-rings is reduced too much to reduce friction or breakaway forces. If too low preload is applied, the important elastic recovery behavior of the O-ring is lost more quickly.

[5] Flow erosion is usually a consequential damage, but it can also have other causes, e.g. lack of pre-compression of the seal.
[6] Translated from MÜLLER, Heinz K. und NAU, Bernard S.: Fachwissen Dichtungstechnik, Chapter 5: Hydraulikdichtungen, P. 30 (Online publishing: www.fachwissen-dichtungstechnik.de , opened on 11.11.2018)
[7] Translated from MÜLLER, Heinz K. und NAU, Bernard S.: Fachwissen Dichtungstechnik, Chapter 8: Wellendichtringe ohne Überdruck, P. 6f. (Online publishing: www.fachwissen-dichtungstechnik.de , opened on 11.12.2018)
[8] translated from RÖTHEMEYER, Fritz und SOMMER, Franz: Kautschuktechnologie, Hanser Verlag, 2001, P. 518f.

2.5 Excessive Axial Strokes Due to Pressure (In Case of Static Seals)

In the event of hard pressure surges in hydraulic systems, seals used statically can also experience abrasion. If the seal bushing has too much axial play, this can lead to considerable abrasion wear due to cyclic loading, despite the short frictional travel of the seal or the O-ring (a few tenths of a millimeter).

2.6 Unsuitable Seal Formulation or Production

For the compound chemist there are many possibilities to influence the abrasion behavior of a mixture.
The quality of the fillers has a great influence. Active fillers are used particularly to minimize abrasion. The "As the polymer-filler interaction becomes more intense while the chemical composition of the fillers remains the same, the larger the filler surface is available to the rubber, regardless of whether this is achieved by increasing the amount of filler or by reducing the size of the filler particles."[9]
Also, the cross-linking system can be used to improve compound properties regarding abrasion resistance.
Likewise, the base polymer and its average molecular weight distribution are of decisive importance. "Rubbers with low Tg [glass transition temperature] or elastomers with low hysteresis [low loss angle δ] show low levels of abrasion."[10] For extreme demands on abrasion resistance, thermoplastic polyurethane elastomers are particularly suitable, which explains their frequent use in hydraulic applications. HNBR materials have the best abrasion resistance in the field of classic elastomers.
The cross-linking density is also a manipulated variable with which a formulation can be optimized. In order to achieve good abrasion resistance, a lower crosslinking density is required. However, this can be associated with losses in other properties, such as a poorer compression set.

2.7 Changed Operating Conditions

A change from lubricants, e.g. from mineral oils to synthetic or biodegradable ones, can be critical. Sometimes these alternative lubricants have poorer tribological properties.
Due to high, originally not intended, loads of a system, seals cannot be supplied sufficiently with lubricant.
Also, deviating temperatures or changed machine programs can lead to increased abrasion and therefore to premature seal failure.

[9] translated from KEMPERMANN, Th.: Vulkasil verstärkende Kieselsäure-Füllstoffe (Chapter D12) in: BAYER AG: Handbuch für die Gummiindustrie, 1991, P. 538
[10] translated from RÖTHEMEYER, Fritz und SOMMER, Franz: Kautschuktechnologie, Hanser Verlag, 2001, P. 518

2.8 Excessive Swelling in Contact Mediums

Excessive swelling can occur if, for example, lubricants are replaced afterwards and their compatibility with the seal material is not checked, or if unsuitable seal materials are used. For dynamic seals, volume expansions of 5-10% are generally permissible, higher expansion rates can lead to problems. The seal increases its contact area due to swelling and softens considerably, which reduces its resistance to abrasion wear.

3. Damage Pattern

3.1 Description of the Damage Pattern and Problematic Areas

In general, after abrasion wear, the damaged seals show a verifiable loss of mass. In addition, a profile projector can be used to measure the cross-sectional area and compare it with the initial seal. A reduced area can hereby be detected with this type of damage.
Two types of damage are most evident in areas where material has been abraded:
Either the damaged surface is smooth and shiny (flat wear) or it shows scoring with or without particle residue.
With abraded seals, the elasticity of the material is normally completely preserved, so there are no signs of aging.

<u>*3.1.1 Damage Pattern "Abrasion due to unsuitable mating surface"*</u>

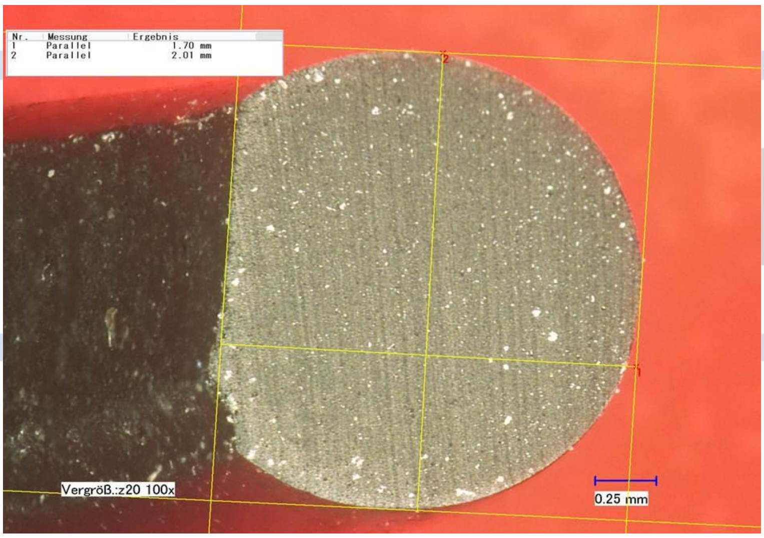

Fig. 1: Excessive abrasion caused by a poor mating surface

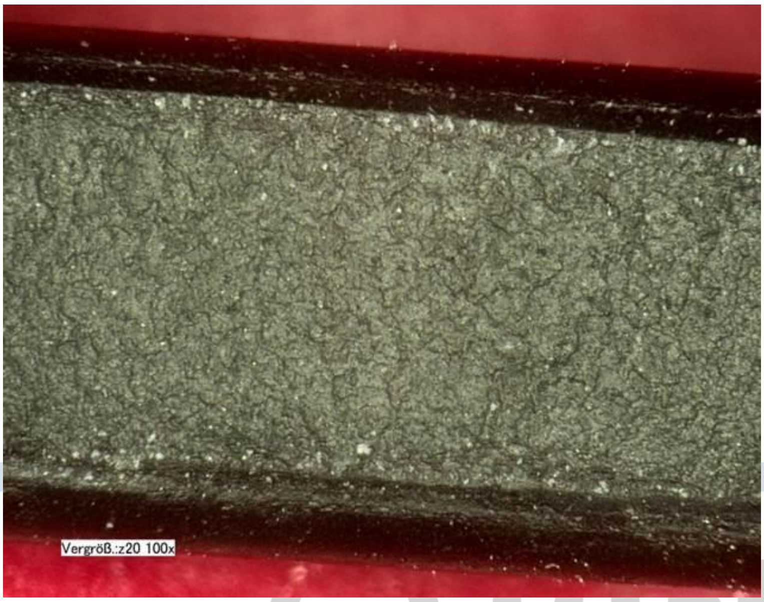

Fig. 2: Frontal view of the abraded area of the O-ring from Fig. 1

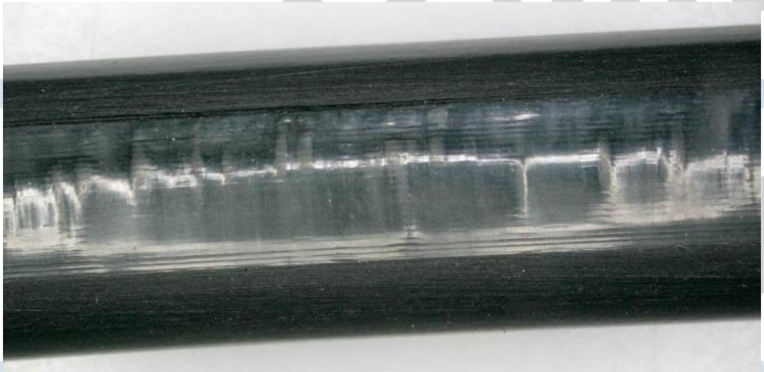

Fig. 3: Unsymmetrically flattened O-ring, the abraded surface is smooth and shiny.

3.1.2 Damage Pattern "Hydroabrasion"

Fig. 4: Inside of a cut EPDM O-ring from a thermostatic valve: Metal particles are clearly visible in the grooves (hydroabrasion).

3.1.3 Damage Pattern "Abrasion due to inadequate lubrication / dry running"

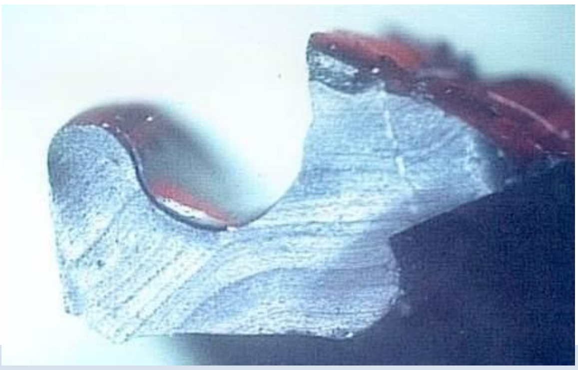

Fig. 5: Heavy abrasion on the sealing lip of a radial shaft seal after dry running or deficiency lubrication and impermissibly high pressure loading

Fig. 6: Original profile of the radial shaft seal from Fig. 5

3.1.4 Damage Pattern "Abrasion due to constructional defects"

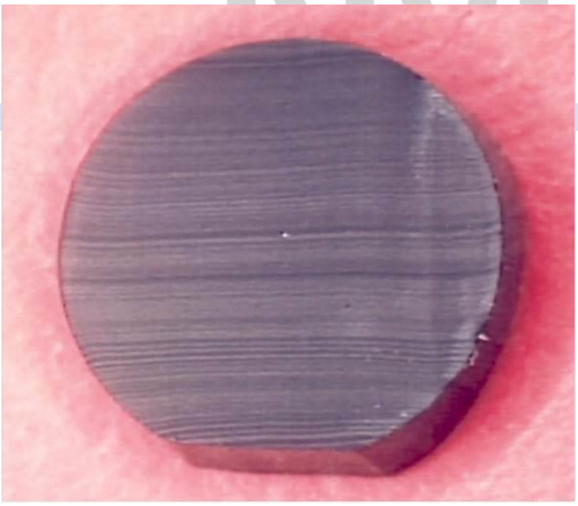

Fig. 7: One-sided flattened O-ring; the abraded surface itself is smooth and glossy. In order to keep friction forces low, dynamically used O-rings are often pressed only slightly. As a result, relatively low abrasion, as on the O-ring shown, leads already to leakage.

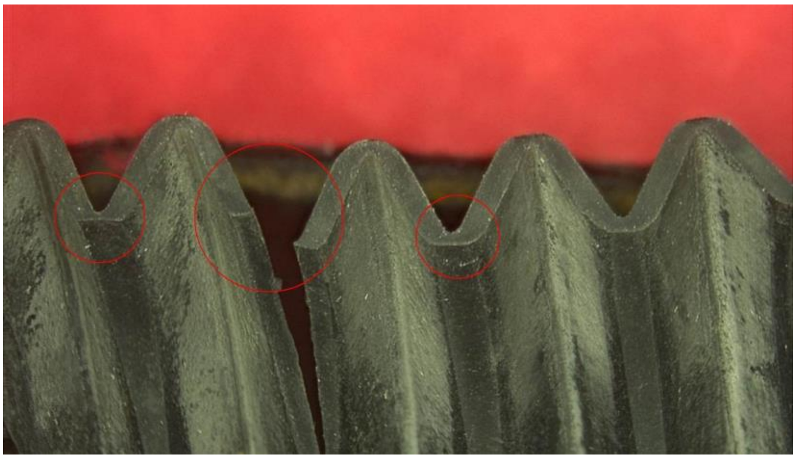

Fig. 8: Rupture of an EPDM bellows due to abrasion (middle red circle), the left red circle shows a heavily abraded area, which is also shortly before the rupture.
This damage can be avoided by reinforcing the material in the critical area or by changing the design to reduce chafing.

3.1.5 Schadensbild „Abrieb durch übermäßige druckbedingte Axialhübe“

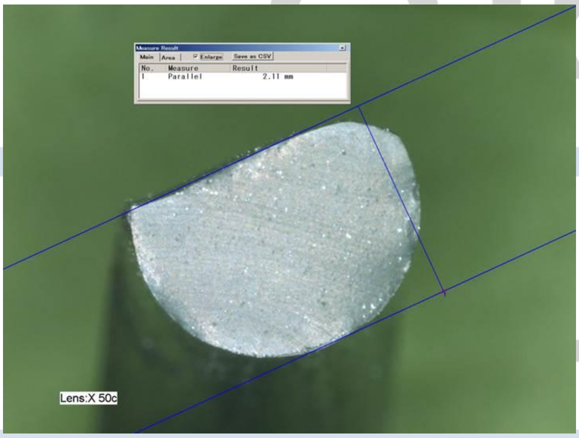

Fig. 9: Abrasive O-ring (EPDM, 70 ShA) made of "static" seal with excessive axial stroke due to pressure; Piston installation space: Piston fixed with steel clamp, yielded 0.5-1 mm under pressure (10 bar), diameter play approx. 0.5 mm, eccentric position

Fig. 10: Top view outside diameter of the damaged O-ring from Fig. 7

3.1.6 Damage Pattern "Abrasion due to unsuitable seal formulation or production"

This cause of failure cannot be derived directly from the damage pattern. This can be seen in the comparison with other formulations or earlier batches.

3.1.7 Damage Pattern "Abrasion due to changed operating conditions"

This cause of failure cannot be directly derived from the damage pattern, but can only be found out through research and professional exchange with the seal user. All that remains is to prove that the seal formulation has not changed significantly compared to previous deliveries.

3.1.8 Damage Pattern "Abrasion due to excessive swelling in contact mediums"

In addition to a softening that has occurred and a decrease in density, an increase in volatile components can be detected in the TG analysis compared with the new state of the seal. If necessary, the source of the swelling can be determined by FTIR analysis (extract analysis) or even better by GC-MS analysis (thermos-desorption).

3.2 Effects of the Damage

The consequences of excessive abrasion are slowly becoming apparent. After initial sweat leaks, leakage increases until the sealing system fails completely.
However, abrasion can also cause ruptures in rubber components, e.g. bellows, if, for example, thin areas are heavily abraded.

3.3 Differentiation from Similar Types of Damage

The damage "Permanent deformation" can at first glance resemble excessive abrasion. However, seals with permanent deformation will usually show symmetrical flattening, no loss of mass and signs of aging (increase in hardness).
Erosion damage to seals caused by excess air or blow-by-effects can create score-like structures similar to hydro-abrasion. However, there are no particle residues in the grooves.

4. Preventative Measures

An important preventive measure against hydro-abrasion is regular oil maintenance and the use of suitable filters to keep the particle load in the oil as low as possible.
If wipers are added to rod seals, they can prevent particles from scoring the piston rods.
Finally, the use of abrasion-resistant, high-quality seal formulations in critical applications is recommended and worthwhile. When purchasing seals, it should be ensured that the supplier does not change the formulation without the customer's permission.

5. Practical Tips (Testing Possibilities / Standard Recommendations)

Over decades of rubber testing, a variety of abrasion test methods have been developed (Akron abrader, abrasion resistance according to DIN ISO 4649, DuPont-Grasselli machine, Dunlop Lambourn machine, Goodyear angle machine, pico abrasion test, and many more), but these are not very helpful for concrete statements in the sealing field. For instance, certain types of plasticizer can cause lubricating effects, which simulate a good abrasion resistance value. These abrasion test methods can only be used to facilitate material pre-selection.
Ultimately, the suitability with regard to abrasion should be demonstrated in test rigs that are as realistic as possible (e.g. for hydraulics or pneumatics), as they are operated, for example, by larger seal manufacturers.

6. Other

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