EXPERT KNOWLEDGE FAILURE ANALYSIS OF ELASTOMER COMPONENTS

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O RING PRÜFLABOR RICHTER

TESTING CONSULTING DEVELOPING

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Incorrect Installation Space –
Details Can Make the Difference

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1. Classification and Frequency of the Damage Pattern

Of the four main damage mechanisms, installation damages are assigned to the third main group, as listed below:

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

The third main group can be divided into three subgroups: incorrect installation space, physical overload due to operating conditions, and installation errors. This fault pattern belongs to the first subgroup and causes approx. 15% of all failures concerning elastomer seals (in more than

2,000 cases of damage investigated by us). It is considered to be the number one main cause for seal failures, mostly due to faulty details.

2. Technical Background Knowledge on the Damage Pattern

A correctly designed installation space is crucial for a functioning seal.
To fully exploit the potential of rubber materials, gaskets should be used in the force shunt if possible, so the degree of deformation is independent of the tightening force of the screw connection. The resulting sealant surface pressure is then additionally increased by the system pressure, depending on the geometry. As a result, the sealant surface pressure of O-rings is always higher than the system pressure, which also qualifies the O-ring as a high-pressure seal up to 400 bar and higher.
Also with other seal types, such as radial shaft seals or hydraulic seals, the installation space has a special function because these seals also only function optimally in a given deformation state of the inner and/or outer diameter or of the sealing profile. In addition to the correct degree of deformation of the seal, the sealing function is ensured to a considerable extent by the surface quality of the installation space.
Elastomer flat gaskets, on the other hand, are only suitable for main force closure at rather low pressures (< 20 bar). Due to the geometry, only a limited pressure activation takes place, whereby the pressure range of the seal is reduced with the compressive stress relaxation that is indispensable for elastomers.

2.1 Degree of Deformation (Compression)

Since elastomers do not have ideal elastic properties but rather behave viscoelastically, their elastic resilience also depends on the degree of deformation. Too little deformation causes a faster loss of the elastic resilience. For this reason, static O-rings are deformed or compressed by at least approx. 10%. With other sealing geometries such as rectangular rings, the minimum degree of deformation may be slightly lower, but not less than 5% of the cross-section.
If the deformation is too high, excessive stresses can occur within the seal at elevated temperatures, which can lead to internal stress cracks which then propagate to the outside. The degree of deformation of the gaskets must therefore be limited upwards. For O-rings with small cord thickness, 40% is still possible with hardness grades of 70 Shore A, but with increasing cord thickness, the susceptibility to stress cracks increases. A measure of the sensitivity to stress cracking is the elongation at break of a material, which should always be at least 100%. The higher the value, the greater the protection against stress cracking at elevated temperatures. However, the maximum possible degree of deformation can also result from the assembly situation, if safe assembly is no longer ensured as a result. As a general rule, the elastic recovery potential of elastomers can only be obtained with appropriate deformation (15-35%).
A defined degree of deformation is, therefore, a basic requirement for a reliable sealing function. The compression must still be sufficiently guaranteed even with unfavorable tolerance positions. For this reason, it must be checked in advance of the application that this is ensured even with the most unfavorable tolerance positions and maximum possible eccentricities.

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2.2 Edge Design

Since the groove materials (e.g. steel, aluminum, glass fiber, reinforced plastics) are much harder and more rigid than rubber materials, sharp edges must be avoided at all costs. These can damage the seal during installation, under pressure impact or in dynamic stress through relative movement. Starting from an edge radius of 0.05 - 0.1 mm, it is no longer referred to as a sharp edge.
Sharp edges produce cracks that begin on the outside of the elastomer component and can then propagate under operating conditions.

2.3 Surfaces

When selecting the suitable groove or flange surface, a distinction must be made between static and dynamic seals. In the case of static gaskets, it is ultimately a question of the degree of tightness to be achieved. This is usually defined by a standardized gas leak rate. The lowest requirement level is a fluid-tightness, which is considered to be secured with a gas leak rate of 10^{-2} mbar l/s. O-rings, on the other hand, have a potential of up to 10^{-6} mbar l/s and higher. If this is to be safely exploited, the structure of the surface (and, therefore, the machining process) should also be specified in addition to the usual surface parameters. Cross structures to the circumferential direction should be avoided. In some fluid systems, these can lead to sweat leakage in combination with dynamic gap changes due to vibrations or pressure surges. With dynamic seals, the surface quality should ensure a minimum of friction and wear. In addition to the roughness depth, the percentage of the contact area is also important. This is the load-bearing proportion of a machined surface in relation to the total surface. For dynamic seals, this should be greater than 50%.

2.4 Gap Dimensions

Regardless of the influence of the gap dimensions on eccentricity (local reduction of deformation, see above), it must be ensured that no impermissible gap impact occurs under maximum pressure. For verification purposes, gasket manufacturers offer diagrams, which show a maximum permissible gap for different material hardnesses and pressure maxima. In case of doubt, support rings should be provided or higher material hardnesses should be selected.

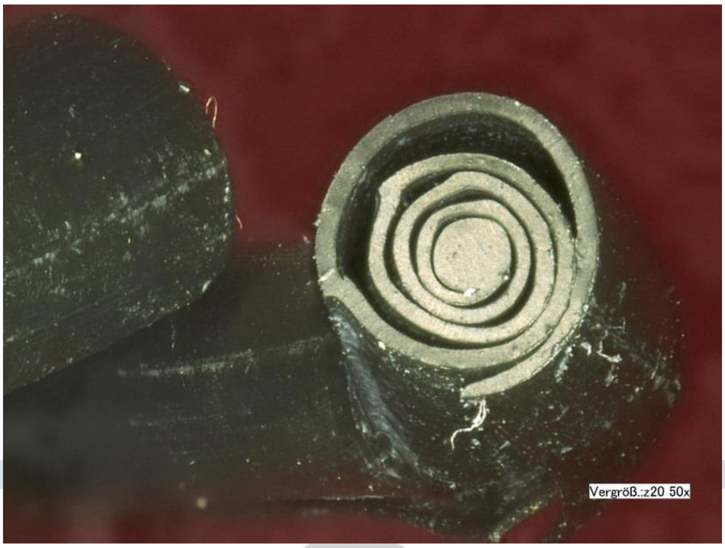

Fig. 1: Effect of a sharp-edged groove design. The O-ring peels off at the groove edge, here under the impact of 350 bar at a gap of 0.05 mm

2.5 Groove Filling

Since elastomers can be considered incompressible at first glance, the installation space must always offer more volume than the seal can take in the worst case. A possible swelling of the gasket, therefore, has to be considered. Typical volumetric groove filling degrees are between 65-85%. Under no circumstances should the theoretical maximum groove filling degree be higher than 95%. A groove filling degree too high increases the assembly risk (damage or compression of the seal) and can lead to a limited pressure activation. The groove filling level is usually set over the groove width.

3. Damage Pattern

3.1 Description of the Damage Pattern and Problematic Areas

A classic groove overfill can be recognized by crushed (already during assembly) or frayed edges. Material drives on both sides are typical for this type of damage.

Fig. 2: O-ring cross-section after a typical groove overfill: The crushed areas can be seen above and below

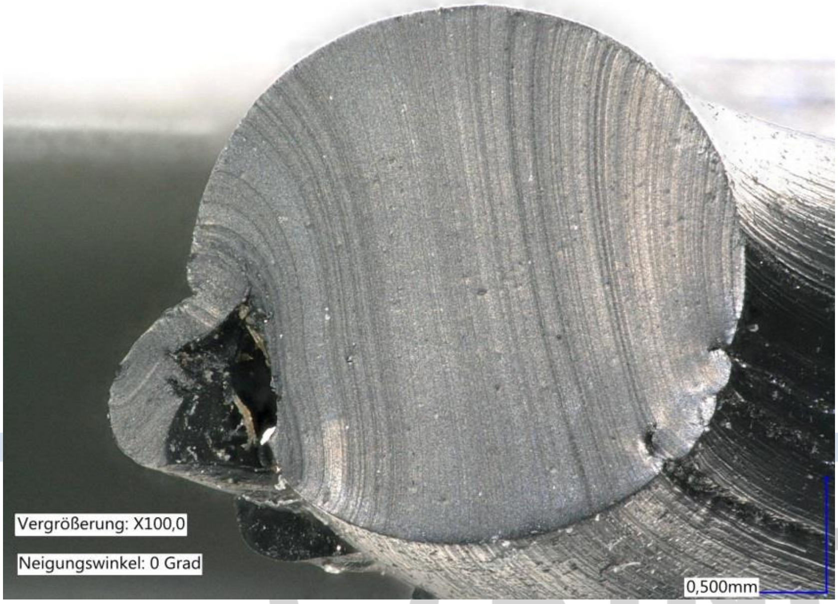

Fig. 3: O-ring cross-section after a groove overfill: On the left, the crushed area can be seen.

If the deformation is too large, stress cracks will appear inside the seal and then propagate outwards.

Fig. 4: EPDM O-ring, destroyed by excessive deformation and thermal impact (stress cracks)

In the case of damage caused by sharp-edged installation spaces, straight-line incisions are often noticeable.

Fig. 5: Incision on a membrane through a sharp edge in the installation space.

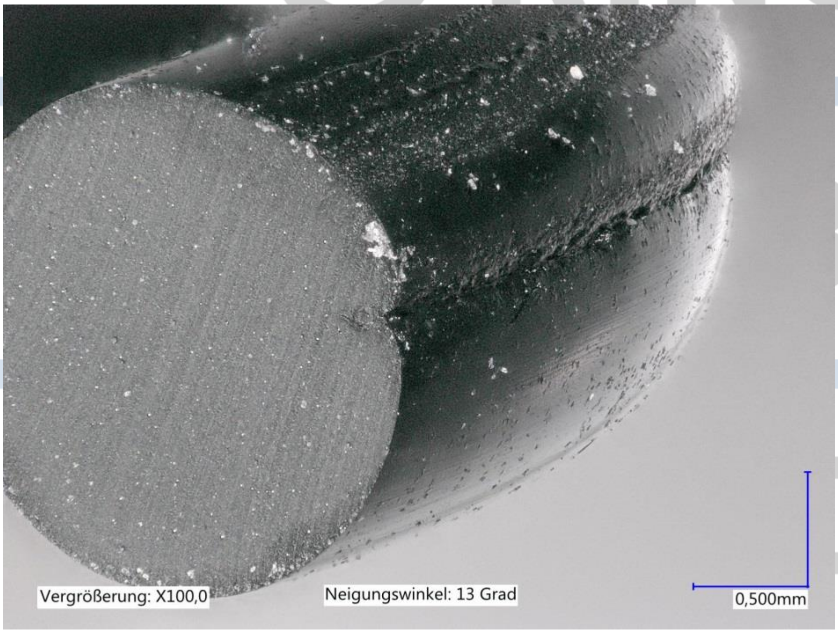

Fig. 6: Cut caused by a sharp edge in a screw-in hole (outside diameter of the groove) of a hydraulic screw connection.

If the seal fails due to a poor surface structure or too little compression, often no damage can be detected on the seal. This error must be determined by an analysis of the surrounding conditions (groove surface, recalculation of tolerance positions and seal compression).

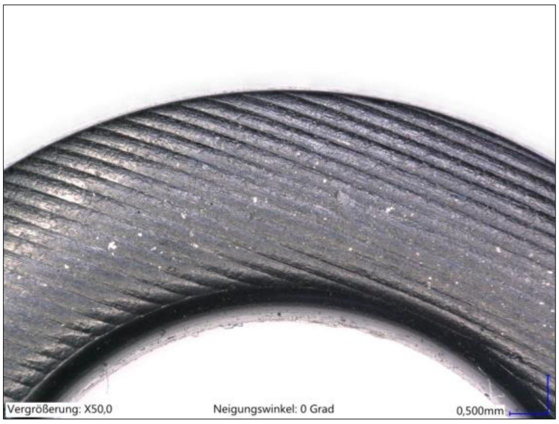

Fig. 7: This reason for failure due to an unsuitable surface structure of the groove can be clearly seen under the microscope, as the poor surface is visibly imprinted on the elastomer: The leakage is caused by the deep scoring in the groove.

3.2 Effects of the Damage

In most cases, incorrect installation spaces lead to failures after brief periods of operation, as the damage occurs right at the start. The cause of failure are usually larger leaks.
However, there are also cases of damage with minor leakages, so-called sweat leakages, which are caused by unsuitable surfaces. These often only occur after several hundred hours of operation. With minimal gas leaks due to a poor groove surface, detection is more difficult. This requires sensitive leakage measurements, such as the pressure difference method or helium leak tests.

3.3 Differentiation from Similar Types of Damage

The damage pattern caused by sharp-edged installation spaces can also be the result of an assembly damage[1] or a manufacturing defect[2]. If this type of incision/crack occurs on a gasket, the three possible faults of incorrect installation space, incorrect assembly and manufacture must be investigated in more detail. As is so often the case in damage analysis, the procedure here is based on the exclusion principle. If the installation space is correct, it can only be an assembly or manufacturing fault.

4. Preventative Measures

The simplest and most effective preventive measure is the training of seal users, especially in the field of design. The time required for this may deter some managers, but functioning and sustainable sealing systems contribute greatly to the economic success of a company.
Furthermore, existing sealing solutions should not be copied one-to-one for new applications. Even the smallest changes can have a severe impact.

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[1] Further information: RICHTER, B. und BLOBNER, U.: Fachwissen Schadensanalyse von Elastomerbauteilen: Montagebeschädigungen – Die oftmals unterschätzte Schadensursache, 02/2018, Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_montageschaeden_02_2018.pdf
[2] Further information: RICHTER, B., BLOBNER, U. und RICHTER, Timo: Fachwissen Schadensanalyse von Elastomerbauteilen: Risse durch Herstellungsprobleme – Ein gravierender Fehler, der oft zum Dichtungsaufall führt, 10/2017, Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_herstfehler_risse_10_2017.pdf

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Whenever surface finishing methods are changed, it should always be checked whether this has changed the functionality of the surface. For applications with critical surfaces (e.g. excessive roughness), a softer seal may help, although at the expense of greater susceptibility to gap extrusion.

5. Practical Tips (Testing Possibilities / Standard Recommendations)

There is a wide range of literature and recommendations for the correct design of installation spaces.
First and foremost, the relevant standards should be mentioned. For O-rings it is **ISO 3601-2** (Edition 2016-07: Fluid power systems - O-rings - Part 2: Housing dimensions for general applications). The German version of this English ISO standard replaced the widely known **DIN 3771-5** (1993-11 edition).

For other sealing types the following standards apply.

- Installation spaces for piston and rod seals in hydraulic cylinders: **ISO 5597** (Edition 2018-05): *Hydraulic fluid power – Cylinders - Dimensions and tolerances of housings for single-acting piston and rod seals in reciprocating applications*
- Installation spaces for wipers in cylinders: **ISO 6195** (Edition 2013-02): *Fluid power systems and components - Cylinder-rod wiper-ring housings in reciprocating applications - Dimensions and tolerances*
- Installation spaces for piston seals with guide rings: **ISO 6547** (Edition 1981-08): *Hydraulic fluid power -- Cylinders -- Piston seal housings incorporating bearing rings -- Dimensions and tolerances*
- Installation spaces for rubber pre-stressed plastic seals: **ISO 7425** (Edition 1989-12): *Hydraulic fluid power -- Housings for elastomer-energized, plastic-faced seals -- Dimensions and tolerances -- Part 2: Rod seal housings*
- Radial shaft seals: **ISO 6194-1** (Edition 2007-09, chapter 8 housings): *Rotary shaft lip-type seals incorporating elastomeric sealing elements - Part 1: Nominal dimensions and tolerances*

Finally, there is a German DIN standard for rotary shaft seals, DIN 3760, which was published in September 1996. Chapter 7 describes "Guidelines for installation".
In addition to the standards, many seal manufacturers offer helpful information on the design of installation spaces. These are available in printed and digital form (e.g. O-ring manuals), but also as calculation software.

6. Other

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