EXPERT KNOWLEDGE OF O-RINGS

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O RING PRÜFLABOR RICHTER

TESTING CONSULTING DEVELOPING

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State of the Art for O-Rings:
Standardization - Testing - Materials

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1. Improved State of the Art for O-Rings Available

Unfortunately, O-ring failures still occur far too often in practice. Over the past 20 years, the O-Ring Prüflabor Richter has carried out well over two thousand failure analysis of elastomer seals, 60% of which were O-rings alone. The main causes of the failures are poor housings, manufacturing defects of the O-rings, assembly errors and poor materials [1], and of course a wide variety of application errors. On the one hand, this is due to the fact that the design of a seal is often underestimated, on the other hand, however, that O-rings are often insufficiently specified. The poor specification of O-Rings can drive purchasers into the hands of inadequately qualified technical dealers, who are lured by global procurement with great prices, but are often unable to adequately check the quality of the goods sold themselves. In the past, this was aggravated by the fact that O-ring standardization (ISO 3601) could not be used to specify materials, nor were there any tolerances for O-rings and the permissible surface deviations for large O-rings (cord thickness > 8.4 mm). It is clear that there is a danger that if the O-rings are not sufficiently specified, the state-of-the-art O-ring suppliers who can exploit the full technical potential will not necessarily be involved. But even if you already purchase from an appropriately competent supplier, you should make sure that you actually specify what represents the state of the art today. With the new edition of ISO 3601-5 (2015), the situation of users with regard to material standardization has improved considerably [2]. Further revisions of parts 1 and 3 of ISO 3601 (which were not yet published) allow the specification of O-rings with large cord thicknesses (8.4-14.00 mm) with regard to dimensional accuracy and permissible limits for shape and surface deviations. If one now also takes into account the state-of-the-art in testing technology, namely that it is also possible to use optical surface testing methods for large O-rings [3], there are considerable advantages for the user from the progress of the state of the art in O-ring technology.

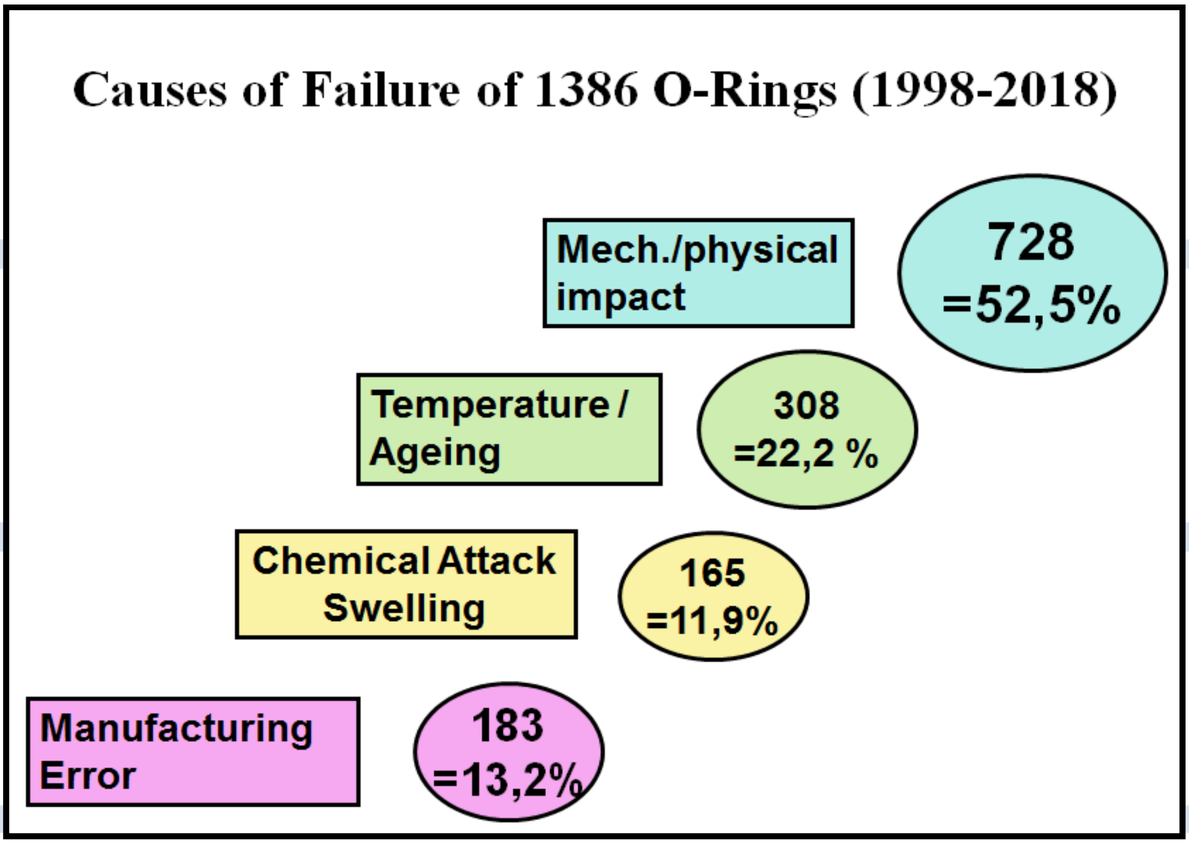

Figure 1: Causes of Failure of 1386 O-Rings

2. Prerequisites for a Good Sealing Function

In order for O-rings to work well, certain requirements must be met. "Good functionality" means

2.1 Sufficiently Tight

For this purpose, it should be specified how "tightness" must be defined in the application. From an application point of view, a rough distinction can be made between fluid-tight, which is usually ensured by a technical tightness of at least 10-2 mbar l/s, and "gas-tight", which normally means a technical tightness of at least 10-4 mbar l/s. The following definitions are used for the definition of "tightness". Sufficient tightness requires sufficient deformation of the O-ring in the groove and defined surface quality of both, the O-rings and the mating surface.

2.2 Sufficient Temperature Resistance

This means that the O-ring remains sufficiently elastic over the planned service life, taking application-specific temperatures into account. In the case of elastomers, the permissible continuous temperature is in principle dependent on the time of loading. Therefore, a safe material selection can only be made if the temperature collective of the application is defined over the entire service life. It must also be taken into account that within the same polymer family (e.g. FKM or EPDM) recipe-specific properties can vary greatly with regard to ageing behavior and low-temperature flexibility.

2.3 Sufficiently Resistant to Environmental Influences (Media Resistance)

The O-ring can only achieve the service life designed under 2.2 if the elasticity is not significantly affected by surrounding media or other environmental influences. Here, too, one cannot rely solely on the correct choice of polymer family, but must make sure that recipe-specific influences are taken into account.

3. Requirements for a Good Sealing Function

The functionality of O-rings is ensured by 3 columns, which represent the gland design, the O-ring itself and the assembly process. Any deviation from the nominal condition means that the potential of the O-ring seal is considerably reduced, resulting in premature failure.

The o-ring seal

Requirements for a good Sealing Function

Gland design	O-ring properties	Assembling
Enough squeeze even at worst case situation reg. tolerances	Keeping the dimensional tolerances	No dirt on sealing surfaces
Good surfaces	Good material properties (compatibility + compression set)	No intermixing of sizes or compounds
No sharp edged surfaces	No critical surface imperfections	No contact with sharp edges
No to big gaps		Do not damage the sealing surfaces at disassembling the o-ring

Figure 2: Requirements for a good sealing function of O-Ring seals

3.1 Requirements for the O-Ring Housing

The housing must ensure that the O-ring cross section is adequately deformed to the fullest extent of all theoretically possible tolerances. If the deformation is too high, the risk of stress cracking increases and the risk of damage during assembly also increases (see also 3.3). If the deformation is too low, the sufficient tightness is endangered due to the too small contact width to the sealing surface (see 2.1), likewise the elastic potential in the O-ring cannot be called up, which can result in a greatly reduced service lifetime (see 2.2). In addition, the housing must avoid overfilling the groove, as elastomers are almost incompressible, sharp edges must be rounded and, when exposed to high pressures, the gap must be small enough to prevent damage due to gap extrusion. If the gap is too large, the local compression of the O-ring can be reduced excessively when the components to be sealed are eccentric. And, of course, to ensure sufficient tightness (see also2.2), it is also essential to specify the surface quality of the sealing surface, if possible in terms of surface roughness and surface structure, which is specified by the machining process. In addition, the gland must be designed in such a way that the O-ring cannot be damaged during assembly. This means that the O-ring must not encounter sharp edges anywhere in the housing or on its way into the installation space. In addition, insertion screams must prevent the O-ring from being sheared off when the components are joined. If this is not possible, the inner diameter of the O-ring should be considerably pre-stretched in the installed condition in order to avoid local pushing out of the O-ring during joining, which could shear the O-ring.

3.2 Requirements for the O-Ring

The basic requirement for the correct function of the O-ring is first of all compliance with the required cross-section tolerance, only in this way can a solid sealing function be maintained over a long period of time by means of the correct degree of deformation (= squeeze). The compliance with the internal diameter tolerance is not quite as important, but deviations from the internal diameter can also indirectly influence the cord thick-ness in the installed condition. Another important basic function of the O-ring is its smooth surface, which is as free of defects as possible. The difficult processability of rubber materials, however, does not permit the eco-nomical, error-free production of O-rings. A distinction must therefore be made between acceptable and not acceptable surface imperfections. The user is therefore dependent on the fact that this good/bad sorting with regard to surface deviations is consistently carried out by the manufacturer. An evaluation of 873 O-ring fail-ures from the last 10 years shows a rate of 15.3% failures due to manufacturing defects[4], which means that this topic has a particularly high practical relevance. However, experience has shown that the most difficult task for users is to assess the material properties of the O-rings, which are ultimately responsible for tempera-ture resistance (see 2.2) and media resistance (see 2.3). This results from a multiplicative combination of for-mulation quality and processing quality (degree of cross-linking). This means that a good recipe alone is not sufficient. If the supplier does not sufficiently assures the process conditions for vulcanization of the O-rings, the best recipe quality may evaporate. In many cases, the elastomer and testing expertise of the user is not sufficient to provide adequate protection against this.

3.3 Requirements for the Assembly

Even if the requirements from 3.1 and 3.2 are perfectly implemented, risks remain during assembly. One risk is that inadequate cleanliness will have a negative effect on the quality of the tightness (see 2.1), which can be particularly important when gas tightness is required. A further risk is the risk of intermixing if different materials of the same dimension are used by the same user or if dimensions differ only slightly (e.g. cord thickness 5.33 and cord thickness 5.0 mm). If assembly tools are used, care must also be taken to ensure that they are free of sharp edges. And wherever O-rings are disassembled again, e.g. for testing or service purposes, care must be taken to ensure that the O-rings are not levered out of the groove with hard, sharp-edged tools, thereby creating scratches in the sealing surface.

4. The O-Ring Standard ISO 3601- Further Adapted to the Needs of Users

A completely new edition of ISO 3601-5 (2015-04) "Specification of elastomeric materials for industrial applica-tions", as well as a revision of part 1 (not yet published at the time of submission) regarding the cross-section tolerances and part 3 (not yet published at the time of submission) regarding acceptable surface imperfections for O-rings of 8.4-14.0 mm cross-section have significantly improved the benefits for users. In addition, minor revisions have also been made to ISO 3601-2 (2016-07) to further improve the benefit for this standard relat-ed to O-Ring housings.

The o-ring as a standardized part

DIN ISO 3601-1:2013-11 (D)

Fluidtechnik - O-Ringe - Teil 1: Innendurchmesser, Schnurstärken, Toleranzen und Bezeichnung (ISO 3601-1:2012 + Cor. 1:2012)

DIN ISO 3601-2:2010-08 (D)

Fluidtechnik - O-Ringe - Teil 2: Einbauräume für allgemeine Anwendungen (ISO 3601-2:2008)

DIN ISO 3601-3:2010-08 (D)

Fluidtechnik - O-Ringe - Teil 3: Form- und Oberflächenabweichungen (ISO 3601-3:2005)

DIN ISO 3601-4:2010-08 (D)

Fluidtechnik_- O-Ringe_- Teil_4: Stützringe (ISO_3601-4:2008)

ISO 3601-5:2015-04 (E)

New- including requirements measured on o-rings (hardness and compression set) + requirements regarding recipe properties

Fluid power systems - O-rings - Part 5: Specification of elastomeric materials for industrial applications

Figure 3: The different parts of the ISO 3601

4.1 The New Part of ISO 3601-5 - A Milestone for Users

The main benefit of this completely new material standard is that both the basic properties of O-ring materials are defined, i.e. there is finally a binding state of the art for O-ring materials, and the degree of cross-linking of the O-rings is also defined. This means that users without their own materials expertise can specify a good state of the art for O-rings independent from any manufacturer. However, this new edition of the ISO 3601-5 is only propagated very cautiously by the O-ring manufacturers, since a manufacturer-independent definition of the formulation qualities and the binding specification of compression set values for O-rings does not strengthen the position of the suppliers with their existing customers. However, this can also enable access for O-ring suppliers to new customers.

Compression Set Requirements for O-Rings

t=24h	NBR S 70	HNBR 75	FKM 70/75/80	EPDM P 70/80
Prüf-T [°C]	100	150	200	150
DVR max, [%] (d2 min.=2,62mm)	35	40	25	30
DVR max, [%] (d2 < 2,00 mm)	40	45	30	35

Compression Set Requirements for Test-Buttons(13x6 mm)

t=336h	NBR S 70	HNBR 75	FKM 70/75/80	EPDM P 70/80
Prüf-T [°C]	100	125	175	125
DVR max. [%]	60	60	40	40

Requirements for Tensile Strength and Ult. Elongation

ISO 37	NBR S 70	HNBR 75	FKM 70/75/80	EPDM P 70/80
Zugfestigkeit [MPa]	12	16	10	10
Reißdehnung [%]	250	200	150	150/120

Figure 4: Requirements on O-rings and materials according ISO 3601-5

Requirements regarding Heatresistance

t=168h	NBR S 70	HNBR 75	FKM 70/75/80	EPDM P70/80
Prüf-T [°C]	100	150	200	150
Änd. Härte [IRHD,M]	max.+10	max. +10	max. 6	max. 12/10
Änd. Zugfestigkeit [%]	+/-25	+/-25	+/-15	+/-40
Änd. Reißdehnung [%]	+/-40	+/-30	+/-25	+/-50

Figure 5: Material-Requirements regarding heat resistance according ISO 3601-5

4.2 Extension of Cross-Section Tolerances (ISO 3601-1) and Limits of Acceptable Surface Imperfections for Thicker Cross-Sections According to Grade N (ISO 3601-3)

Due to this extension to cross-sections from 8.4 to 14 mm, there are now also manufacturer-independent limits given, which is of course an enormous help for users of large O-Rings for containers. This shows the state of the art and makes the definition of the quality of large O-rings much easier. For example, the cord thickness tolerances for O-rings with a cord thickness of 10 to 12 mm have been set at +/-0.25 mm, the acceptable limits for the length of non-fills at 2.5 mm and the depth at 0,16 mm.

5. State of the Art in Conformity Testing of O-Rings

Using state-of-the-art technology for O-rings means, on the one hand, providing appropriate specifications and, on the other, ensuring that the supplier complies with the specifications. One challenge facing many us-ers is that they do not have their own technical and testing expertise in the field of elastomers. This is the classic way to rely on the suppliers' test reports. This presupposes on the one hand that the supplier must be able to do this at all, which is often only the case to a limited extent with technical dealers, and on the other hand this naturally represents a risk for the user if he relies exclusively on supplier information without counter-checking. In doing so, he may not comply with his legal duty of care. For this reason, material conformity as-sessments are frequently carried out by accredited testing laboratories today, which have a reliable testing competence. In the ideal case, a profound technical competence is also available to evaluate the results for the user in case of doubt. The O-Ring test laboratory is an example that the market for this service has grown continuously. It becomes more difficult with the conformity tests regarding shape and surface deviations of O-rings.

5.1. State-of-the-Art in Material Conformity Assessment

The test methods used to evaluate recipe quality have in some cases been in use for over 100 years [5], i.e. proven test methods are used here. In this context, innovation means testing in an accredited environment and thus improving the resilience of the results or minimizing the risk of incorrect measurements [6]. Where one can then already profit more from the state of the art, is in the application of modern analytical test methods to describe or identify the composition of initial samples in order to be able to check serial samples for deviations in cases of doubt

5.2. State-of-the-Art in Conformity Testing of Dimensions and Surface Imperfections

In contrast to the material testing standards, a rapid progress in technology has taken place here. For about 20 years, the market has been offering automated inspection machines which, in addition to dimensional test-ing, also carry out surface testing for inadmissible deviations. And this technology is continuously developing and is now available for micro-dimensions, e.g. for use in smartphones as well as for large inner diameters (>500 mm) and for large cord thicknesses up to 14 mm [3].

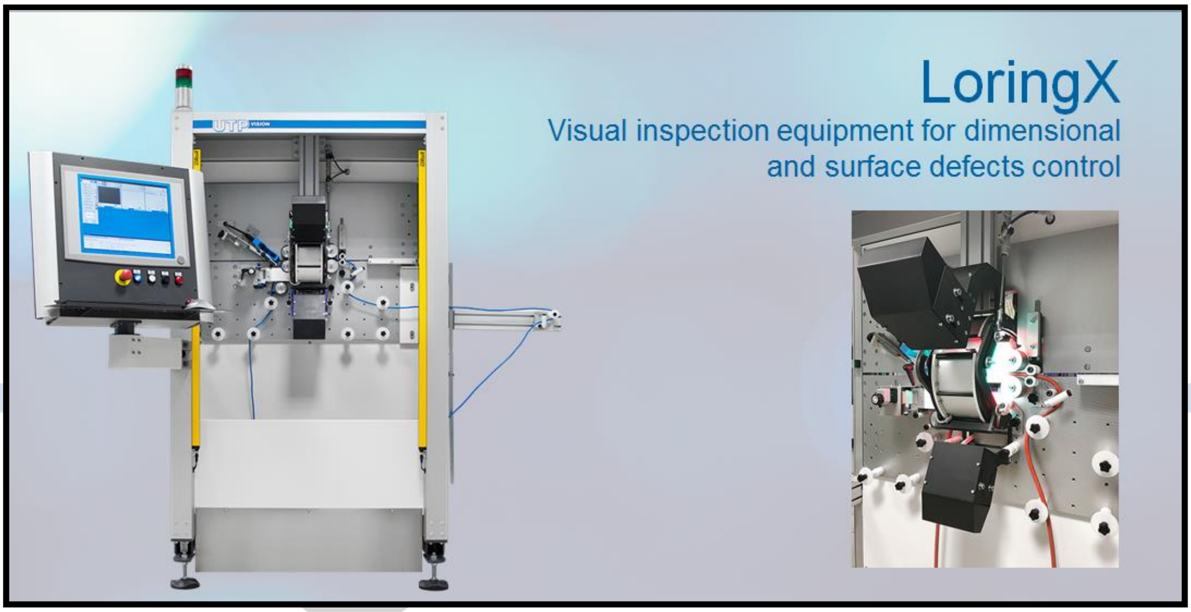

Figure 6: State of the art of visual and dimensional inspection of large diameter O-rings [3]

6. Literature References

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[3] M. Regazzoni, UTPVision S.r.I. Optische Prüfmöglichkeiten für Dichtungen/O-Ringe, lecture during O-Ring Forum, 20./21.6.2018 in Mannheim

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[5] U.Blobner, B.Richter, Indispensible Rubber Tests Yesterday and Today – Looking back on more than 100 Years of History of Rubber Testing from the Perspective of the New O-Ring Standard ISO 3601-5, lecture during the 19th international Sealing Conference ISC on 12nd/13h .October 2018 in Stuttgart/Germany

[6] ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories

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