EXPERT KNOWLEDGE
FAILURE ANALYSIS
OF ELASTOMER COMPONENTS

An offer of

O RING PRÜFLABOR RICHTER

TESTING CONSULTING DEVELOPING

Source: www.o-ring-prueflabor.de
Information as of 02/2018
Version 1

Assembly Damages –
An Often-Underestimated Cause of Damage

Authors:
Dipl.-Ing. Bernhard Richter,
Dipl.-Ing. (FH) Ulrich Blobner,

1. Classification and Frequency of the Damage Pattern

Of the four main damage mechanisms classified by us, assembly damage is assigned to 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: incorrect installation space, physical overstrain due to operating conditions and assembly errors, whereby the percentage of mechanical/physical damage is the smallest group.

From an evaluation of over 2000 damage cases processed and analyzed in the O-Ring Prüflabor Richter, assembly damage was the cause of failure for a seal in approx. 10% of cases.

2. Technical Background Knowledge on the Damage Pattern

The risk of assembly damage to O-rings and other elastomer seals can be largely ruled out by means of an assembly-friendly design of installation spaces, the use of assembly greases and coatings and the use of assembly aids. Regular failures are caused by assembly damage, which shows that this topic is often underestimated. In practice, it is important to interpret the failure patterns correctly in order to identify the real cause.

Before rubber components are assembled, it must be certain that the necessary component cleanliness, drawing specifications, and agreed assembly procedures are adhered to. Therefore, it is important that the grooves in which the elastomer component is to be installed are free of impurities and manufacturing residues such as metal chips.[1] But the cleanliness of the seals themselves must also be taken into account. WÖßNER writes in his dissertation, “Automatic Assembly of O-rings”, published in 1993: "As the analysis shows, manual assembly mainly causes errors due to dirty base parts".[2]

2.1 Damage Due to Lack of Greasing or Unsuitable Lubricants

If there is no lubricant coating intended for installation, or if the oiling of a seal has been forgotten before installation, this can lead to problems such as over-compression, material chipping, cracks or twisted seals.

In addition, the assembly process is not reproducible due to the lack of lubrication as it may vary from batch to batch of seals.

The swelling mechanism caused by unsuitable oil or grease should not be discussed here, as it is described in more detail under "Chemical degradation and Swelling".[3] For the sake of completeness, however, it should only be mentioned that even brief and usually only minor contact with unsuitable assembly oil/elastomer pairs can lead to increased swelling, which can impede assembly or cause it to become defective.

2.2 Mounting-Related Over-Compression and Impressions of the Housing

Usually, products made of elastomers are used in components that have a much greater hardness than the rubber sealing elements. Due to the high elasticity of gaskets and the high stiffness of metal flanges, over-compression may occur which is not noticeable during the assembly process.

---

[1] Vgl. Firmenschrift von Busak+Shamban: O-Ring, Ausgabe März 2005, S. 39 (Webseite abgerufen am 27.12.2017: https://www.uni-kassel.de/maschinenbau/fileadmin/datas/fb15/IMK/LMT/Download/Normen/katalog-O-Ring_Busak_Shamban.pdf)

[2] translated from WÖßNER, Johannes F.: Automatische Montage von O-Ringen, Springer Verlag, 1993, S.86

[3] RICHTER, Bernhard und BLOBNER, Ulrich: Fachwissen Schadensanalyse: Chemischer Angriff und Quellung, Ausgabe 06/2017
Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_chemangriff_quel_06_2017.pdf

Crushing is a relatively easily recognizable assembly damage caused by incorrect positioning during assembly. The crushed areas can be either remain connected to the rest of the seal or completely separated from it. They differ from operational gap extrusion strips by being significantly thicker than these. In addition, over-compressed areas can sometimes show impressions of the housing. Even if this only slightly damages the seal, the over-compressed rubber particle may be trapped between the cover and the housing that is in the main force fit. If a physical relaxation of this trapped particle occurs, in other words, if it begins to creep, the screw connection becomes loose, which can then lead to leakage. Therefore, when designing gaskets or gasket grooves, care must be taken to ensure the gasket is securely positioned between the assembly of the gasket and the joining of the two components to be sealed. Holding studs on the gasket, for example, can contribute to this. Also, special groove shapes (half or whole trapezoidal groove) can help, even if this is a more expensive option.
Another form of crushing occurs when a piston part is inserted into a cylinder part and the piston part is poorly guided or can be dipped obliquely into the cylinder part (**Fig. 1**).

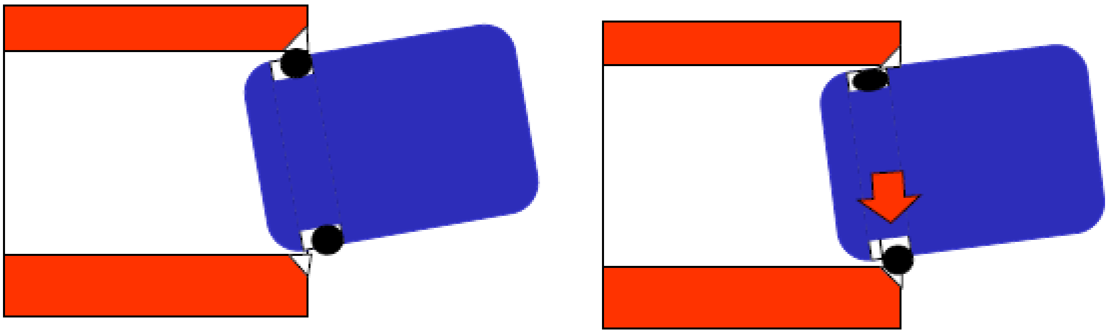

Fig. 1: Incorrect mounting of a piston in a cylinder: The O-ring lifts off due to the tilting in the lower area and is sheared off (Photo: O-Ring Prüflabor Richter GmbH)

The material displaced by the deformation of the seal moves in the circumferential direction, which can lead to partial lifting of the seal at the opposite point. This greatly increases the risk of assembly damage or partial shearing of the seal. If this oblique insertion of the piston cannot be avoided, e.g. by a mounting aid, the seal should be provided with a high installed internal diameter expansion. Experience shows that O-rings with approx. 70 IRHD-M with an installed inner diameter expansion of 20-25% are very robust against this damage pattern because the high elongation leads to a high deformation resistance in the circumferential direction and the displaced sealing material shifts in the axial direction.

2.3 Material Chippings and Cracks

Since rubber seals have to be deformed considerably during the assembly process, the high assembly forces required can lead to high line pressures at the edges of the installation space, especially with non-lubricated installations. If these edges are not well rounded or chamfered, this can already lead to cuts during assembly.

O-Ring Prüflabor Richter GmbH
Kleinbottwarer Str. 1
71723 Großbottwar

Telefon 07148 / 16602-0
Fax 07148 / 16602-299
info@o-ring-prueflabor.de
www.o-ring-prueflabor.de

2.4 Damage Due to Excessive Expansion (External Mounting)

The load limits of sealing materials with regard to elongation at break specified in data sheets represent impermissibly high loads for assembly. As an upper limit, 50% of the elongation at break should not be exceeded. The inhomogeneous structure of sealing materials leads to the fact that the relative standard deviation in the elongation at break can be up to 15% of the median elongation at break in a controlled, scheduled production. The safety factor should be at least 3 times the standard deviation, which is a maximum of 55% of the average elongation at break. Very fast expansions increase the risk of cracks because this also leads to higher stresses.
In the automatic assembly of O-rings, systems with six expanding fingers are often used "which expand the sealing ring into a hexagon. The spanner surface of the hex must be large enough to allow the part to pass through without damaging the ring. This will cause the gasket to expand considerably."[4]
If fewer expanding fingers are used, the necessary expansion increases to obtain the desired "spanner surface".
If high mounting expansions cannot be avoided, a sufficient relaxation time after mounting should be ensured.[5]

2.5 Twisted Seal

This error occurs mainly with O-rings. Unstable O-rings (small cord thickness, large inner diameter) tend to roll or twist during assembly.[6] Or to put it another way: with certain dimensions it is almost impossible to mount O-rings without any twisting. Since the burr area of the O-rings according to ISO 3601-3 may only have limited recesses, O-rings can function without any problems in many applications in the twisted state, whereby a "natural" twist is regarded as a maximum of one turn over the entire circumferential length.
O-rings twist easily due to the flexing of the O-rings during pressure activation in high pressure applications. Therefore, twisting by assembly is not considered a mounting error until either an O-ring application is very demanding in terms of gas tightness, or the twisting is more than one turn over the entire circumferential length.

2.6 Damage Due to Faulty Feed During Automatic Assembly

Non-dimensionally stable gaskets can cause problems during the automatic feeding of gaskets. "These sealing rings are called "large" by their very nature, which essentially means the unfavorable cord thickness to diameter ratio. The rings run only conditionally in vibratory bowl feeders, the danger of running into each other and heaping up is great." [7]

---

[4] translated from JÜLICHER, F.-W.: Dichtungsmontage automatisch – aber richtig! in: KIEFER, S. und BERGER, K.-F. (Hrsg.): Dichtungstechnik Jahrbuch 2010, ISGATEC, Mannheim, 2009, S. 289
[5] Vgl. PARKER-PRÄDIFA: O-Ring Handbuch, Ausgabe 07/2015, S.19 (Online verfügbar: https://www.parker.com/literature/Praedifa/Catalogs/Catalog_O-Ring-Handbook_PTD5705-DE.pdf)
[6] Vgl. PARKER-PRÄDIFA: O-Ring Handbuch, Ausgabe 07/2015, S.19 (Online verfügbar: https://www.parker.com/literature/Praedifa/Catalogs/Catalog_O-Ring-Handbook_PTD5705-DE.pdf)
[7] JÜLICHER, F.-W.: Dichtungsmontage automatisch – aber richtig! in: KIEFER, S. und BERGER, K.-F. (Hrsg.): Dichtungstechnik Jahrbuch 2010, ISGATEC, Mannheim, 2009, S. 287

Extreme deformation of the seals in the event of a material jam in the conveyor unit can result in damage to coatings, which reduces assembly safety. Or, in the worst case, the seal itself may be damaged, which is no longer noticed before assembly.

2.7 Inadmissible Manual Damage

This is often a cause that is difficult to explain. Since the damage caused by individual workers or temporary workers is usually not systematic, the cause must be traced by the best possible limitation of the assembly period and by clever questions and combinations of the damage analyst. Such cases in particular require a high degree of experience and knowledge of everyday production in order to develop a resilient damage hypothesis.

3. Damage Pattern

3.1 Description of the Damage Pattern and Problematic Areas

It is common for assembly errors to cause failure within a short operating time (usually <100 h). Since this is also characteristic of manufacturing faults, it is often necessary to distinguish between these two fault patterns. Occasionally, the damage pattern of gap extrusion caused by pressures that are too high and gap dimensions that are too large also resembles that of assembly damage (crushing due to misalignment).

3.1.1 Damage Pattern " Over-Compression " due to Incorrect Positioning

Over-compression (see **Figs. 2 and 3**) is easy to detect as assembly damage because it is caused by incorrect positioning during assembly. The over-compressed areas can either be connected to the rest of the seal or be completely separated from it. They differ from operational extrusion tags because they are thicker than normal. In addition, over-compressed areas can sometimes show impressions of the housing.

Fig. 2: Crushing due to incorrect positioning of the seal

Fig. 3: O-ring with crushed area during assembly

3.1.2 Damage Pattern "Material Chipping and Cracking "

This is probably the most common assembly error. It "is usually a case of violent cracks, which have a regular, rather slightly rough fractured surface. The degree of roughness also depends on the tear resistance of the material. Fractures caused by manufacturing, on the other hand, show inhomogeneous, often relief-like raised areas in the fracture surface. The crack origin in assembly cracks shows a conspicuously linear beginning (see **Figs. 7 and 8**), and there is also no rounded transition from the surface to the crack in the case of damage caused by sharp-edged assembly spaces. Slightly rounded edges show an impression and/or slight plastic deformation.
Assembly-related cracks show typical load-related crack patterns, which can be explained by the assembly space and process".[8]

[8] RICHTER, Bernhard; BLOBNER, Ulrich und RICHTER, Timo: Fachwissen Schadensanalyse: Risse durch

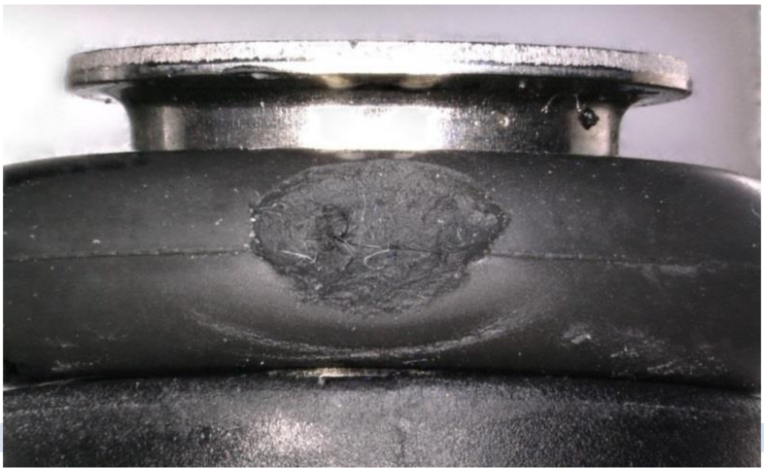

Fig. 4: Material chipping caused by assembly:

Since rubber seals have to be deformed considerably during the assembly process, the high assembly forces required for this can lead to considerable line pressures at the edges of the assembly space, especially if the assembly is not lubricated. If these edges are not neatly rounded or chamfered, this can already lead to a cut during assembly, see **Fig. 7**.

Fig. 5: Part of an O-ring sheared off by assembly

Herstellungspro-bleme, Ausgabe 10/2017, S.17, Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_herstfehler_risse_10_2017.pdf

O-Ring Prüflabor Richter GmbH
Kleinbottwarer Str. 1
71723 Großbottwar

Telefon 07148 / 16602-0
Fax 07148 / 16602-299
info@o-ring-prueflabor.de
www.o-ring-prueflabor.de

Geschäftsführer:
Dipl.-Ing. Bernhard Richter
Ust-ID-Nr. DE 277600966
Steuer-Nr. 71342/02407 FA LB

Sitz der Gesellschaft:
Großbottwar
Amtsgericht Stuttgart
HRB 737482

Volksbank Ludwigsburg
IBAN DE96 6049 0150 0820 5810 03
SWIFT GENODES1LBG

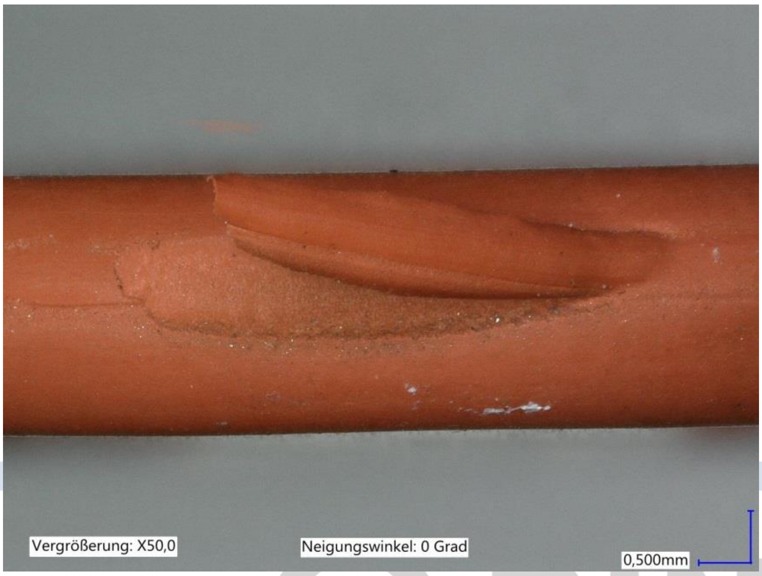

Fig. 6: Shearing off during non-centric insertion due to a local accumulation of material

Fig. 7: Assembly-related crack due to the impact of a sharp edge in the installation space

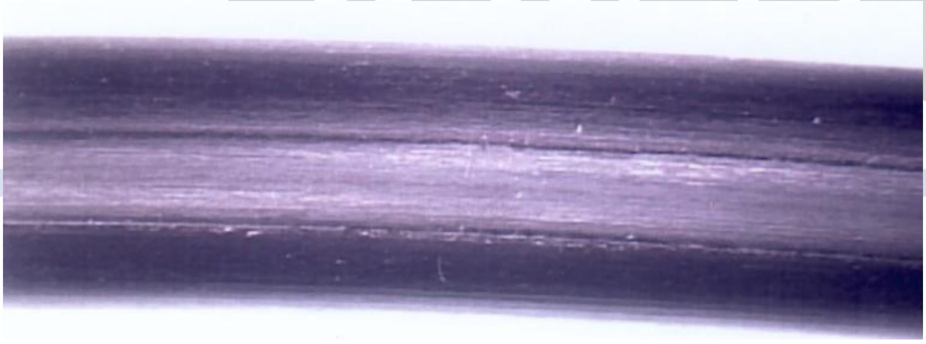

Fig. 8: Crack caused by a sharp edge during assembly

3.2 Effects of the Damage

The effects of assembly damage can be very diverse. While in many cases minor damage is not noticed or is only noticed during maintenance intervals, cracks, large material chippings or twisted rings can quickly lead to leaks or total failure of the sealing system.

Non-systematic assembly damage in particular is a critical cause of damage in demanding applications and difficult to repair.

3.3 Differentiation from Similar Types of Damage

As mentioned above, the challenge for the sealing specialist is to clearly differentiate the assembly error from the manufacturing error, and in some cases, from assembly-induced overstress, causing violent fractures due to excessive widening, for example. In contrast, the differentiation from other damage mechanisms can often be made solely on the basis of the time until failure, which is very small in the case of assembly errors.

In the following, assembly-related cracks should be distinguished from production-related cracks due to faulty vulcanization.

3.3.1 Distinction from Manufacturing Cracks Due to Faulty vulcanization

"In the event of faulty vulcanization, the inhomogeneous fracture surface and flow lines may appear on the seal. This ensures the assumption of manufacturing defects as the cause of the crack. (…)
Cracks resulting from flow lines are often parabolic and symmetrical to the parting line (see **Fig. 9**). If vulcanization is faulty, an inhomogeneous fracture surface is usually visible (see **Fig. 10**). Sometimes conspicuously smooth areas can also be found in the fracture surface. A rounded transition from the surface to the crack (see **Fig. 11**) is also typical for damage caused by vulcanization defects, compared to a case of damage caused by a cut."[9]

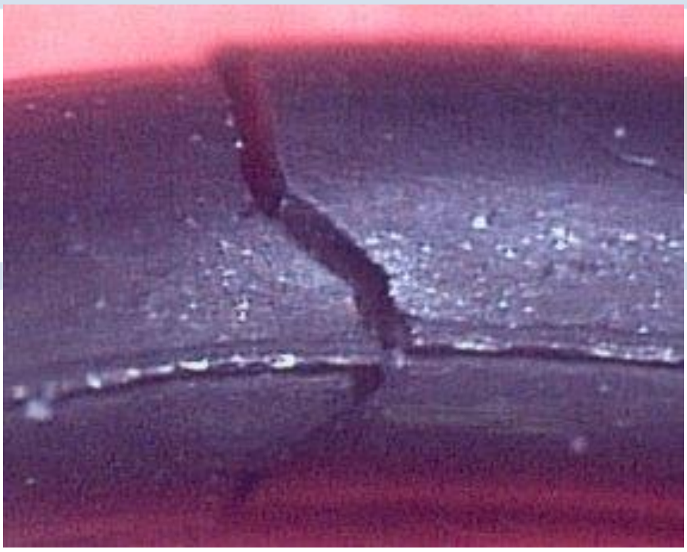

Fig. 9: Manufacturing crack, parabolic and symmetrical to the mold parting line

[9] translated from RICHTER, Bernhard; BLOBNER, Ulrich und RICHTER, Timo: Fachwissen Schadensanalyse: Risse durch Herstellungsprobleme, Ausgabe 10/2017, S.6ff., Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_herstfehler_risse_10_2017.pdf

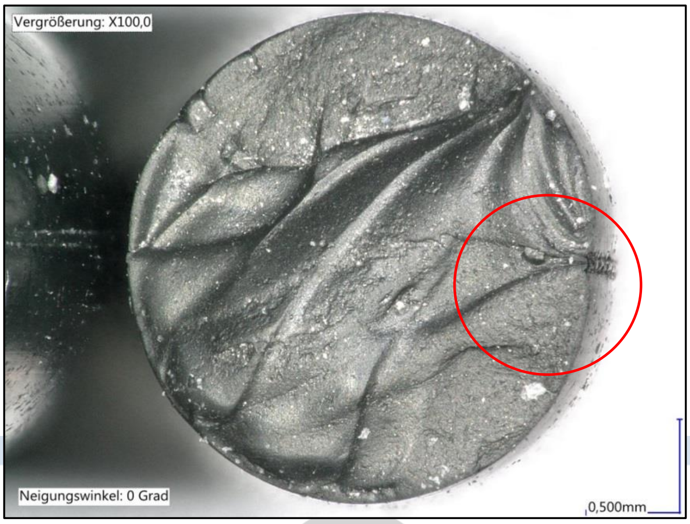

Fig. 10: Ruptured O-ring due to vulcanization defect: Inhomogeneous and fissured fracture surface

Fig. 11: Vulcanization defects due to manufacturing: Rounded crack transition

For further information on how to distinguish cracks other than manufacturing cracks (such as ozone cracks or fatigue cracks), see the article, "Failure Analysis: Cracks Due to Manufacturing Problems".[10]

4. Preventative Measures

In order to avoid assembly errors with O-rings, please refer to ISO 3601-2 with regard to the design of lead-in chamfers and edge radii. These specifications can also apply to other seals as guide values. Manufacturer's specifications and instructions are often helpful in practice. In

[10] translated from RICHTER, Bernhard; BLOBNER, Ulrich und RICHTER, Timo: Fachwissen Schadensanalyse: Risse durch Herstellungsprobleme, Ausgabe 10/2017, S.14-18, Onlineveröffentlichung: http://www.o-ring-prueflabor.de/files/fachwissen_schaden_herstfehler_risse_10_2017.pdf

addition, designers are particularly recommended to take advantage of the range of expert seminars.[11]
The lead-in chamfers should be between 15° and 20°. Sharp edges and transitions must be removed. This should also be explicitly noted in the drawing.
Pistons with externally mounted seals that are to be inserted into cylinders must have a sufficiently long guide in front of the seal to prevent tilting during assembly. (see **Fig.1**)
When planning an automatic assembly, it is advisable to work together with automation companies that already have experience with the assembly of rubber parts. It is a sign of competence when automation companies request not only seals but also a material data sheet during the design phase.
Before assembly, check that the grooves are clean and free of impurities such as chips.
In order to obtain defined and reproducible conditions during assembly, the use of a suitable lubricant is recommended.
For internal installation, it is advisable to avoid running over bores. If this cannot be avoided, the holes should either be well deburred or even better constructively repositioned from the sliding plane of the seal to be installed with "tapered transitions"[12]. It is also possible to use a mounting sleeve to cover the bore during the insertion of the seal. [13]
For internal mounting, it may be necessary to roll in the seal to get it into the hole. It is important not to create local stress peaks. If the nephritic form[14] has proved its worth, it can be produced with the aid of a prefabricated gauge and generously dimensioned radii ensure that the seal is not overstressed locally. Greater caution and experience are required when using gripping pliers.
For outdoor installation, it is important to ensure that the seal is not overstretched.
In general, special tools with rounded edges are recommended for the assembly and disassembly of O-rings to prevent damage to the seals. Various models from various seal manufacturers are available on the market.[15]
Generally, O-rings that have been dismantled should not be reused.

5. Practical Tips (Testing Possibilities / Standard Recommendations)

If, in the event of a failure the cause of the damage cannot be clearly traced back to an assembly fault, it is advisable to consult an independent specialist in order to be able to reliably

[11] Seminar des O-Ring Prüflabor Richter zu O-Ringen: http://www.o-ring-prueflabor.de/de/seminare/o-ring-dichtungen-auslegung-einsatzgrenzen-und-anwendungen/
[12] translated from MÜLLER, Heinz K. und NAU, Bernard S.: Onlineveröffentlichung: www.fachwissen-dichtungstechnik.de , Kap. 3: O-Ring: Theorie und Praxis, Stand: 08/2016, S.8 (Zugriff auf Webseite am 27.12.2017: http://www.fachwissen-dichtungstechnik.de/PDFs%2008.16/fw-dt_Kapitel03_08_16.pdf)
[13] PARKER-PRÄDIFA: O-Ring Handbuch, Ausgabe 07/2015, S.9, Bild 2.31 (Online verfügbar: https://www.parker.com/literature/Praedifa/Catalogs/Catalog_O-Ring-Handbook_PTD5705-DE.pdf)
[14] Firmenschrift der Westring Dichtungstechnik: Montage- und Demontagehinweise für Dichtungsmanschetten, S.3 (Zugriff auf Webseite am 29.12.2017: http://www.westring-dichtungstechnik.de/pdf/Westring_Dichtungstechnik_Montagehinweise_D.pdf)
[15] Z.B. Firmenschrift der Westring Dichtungstechnik: Montage- und Demontagehinweise für Dichtungsmanschetten, S.4 (Zugriff auf Webseite am 29.12.2017: http://www.westring-dichtungstechnik.de/pdf/Westring_Dichtungstechnik_Montagehinweise_D.pdf)
PARKER-PRÄDIFA: O-Ring Handbuch, Ausgabe 07/2015, S.68, Bild 2.31 (Online verfügbar: https://www.parker.com/literature/Praedifa/Catalogs/Catalog_O-Ring-Handbook_PTD5705-DE.pdf)

exclude manufacturing defects as the cause of the failure or, if necessary, to be able to represent the defect pattern confidently in dealings with the seal supplier.

6. Others

This article was published in a short version in the journal DICHT! issue 01/2018. (German)

O RING

PRÜFLABOR

RICHTER