O-ring failure: The true causes

An evaluation of more than 500 failure analyses

Due to machine stops, recall campaigns or environmental damage, O-ring failures cause direct and indirect follow-up costs of hundreds of millions each year. But the resulting damage to a companies' public image may even be worse than the direct costs.

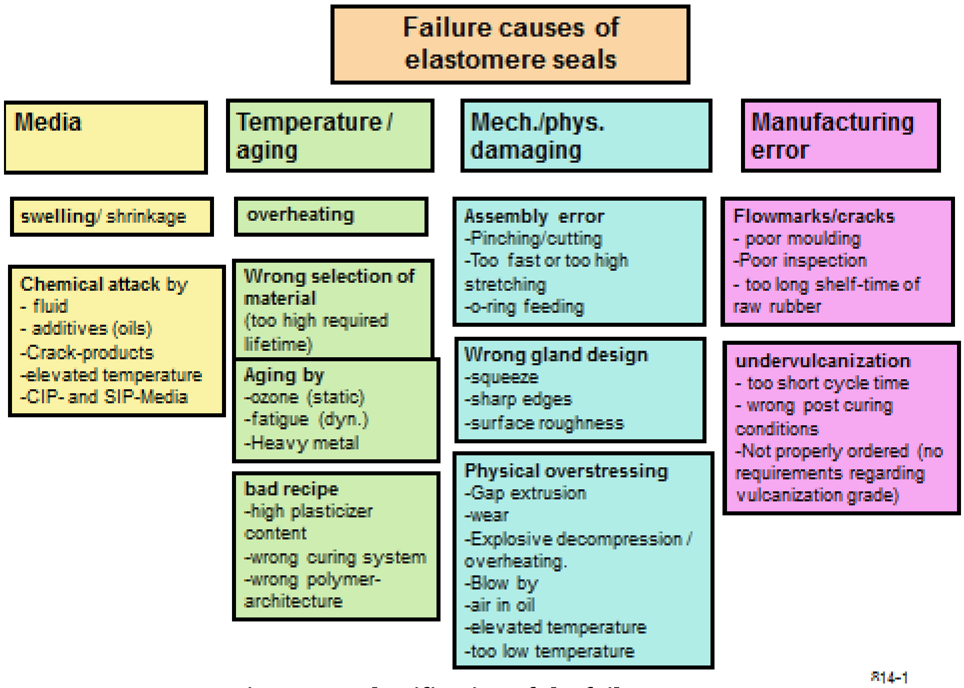

Figure 1 – Classification of the failure causes

A good O-ring seal is a seal that causes no problems and is therefore hardly recognized by the end user. But even though an O-ring is a very simple type of seal it can be a hard way to get an O-ring to not causing any problems. A good way to avoid mistakes during the design and dimensioning phase of an O-ring is to study mistakes made in the past and to learn from them.

Requirements

To learn from mistakes made in the past, the causes of the O-ring failures have to be identified; however it is not easy and sometimes even not possible to find a complete satisfying explanation of the failure. But as every damage mechanism leaves characteristic traces it is possible to explain the failure up to a certain extend and to develop remedial measures to avoid the failure in the future. The difficulty in carrying out a correct failure analysis is to find those traces and to interpret them properly. This is only possible if one knows the loading of an O-ring caused by assembly, clearance and operating conditions. Furthermore, one has to know the material "rubber" good enough to assess its resistance against various loadings correctly, considering the influence of recipe and production of the material. Therefore, a good physical and chemical understanding is absolutely necessary and an appropriate professional experience in the rubber industry may be very helpful.

A failure analysis should be an open-ended process, what implies that the motivation of the executer should not be to blame a certain party but to find the true causes of the failure and to avoid them in the future. Therefore, an independent testing institute has all the prerequisites that are necessary to carry out a good and effective failure analysis. This fact may explain that more than 1000 failure analysis where carried out by the O-ring-Prüflabor Richter during the past 12 years, whereby more than 500 of them concerned O-rings or O-ring-like seals (X-rings, rectangular rings).
In the following, the failure causes are being analyzed, without talking about the characteristics of the damage causing mechanisms in detail. The goal of this article is to describe the actual situation concerning the failure causes of O-rings so that the right conclusions to avoid O-ring failures can be drawn. This article doesn't explain how the results were achieved in particular. For this purpose, the attendance of specific trainings, as offered by O-Ring Prüflabor Richter and others, is recommended.

Classification of the failure causes

The classification of failure mechanisms in four different classes has proven to be useful (**Fig. 1**):

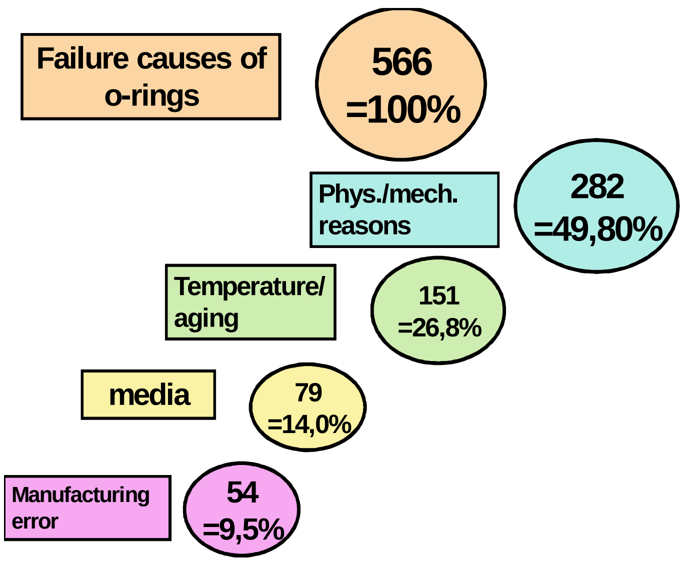

Figure 2 – distribution of failure causes

Medium

Damages by either a strong swelling (strong shrinkage in some special cases) or chemical effects like loss of elasticity, significant cracks and/or strong permanent deformation.

Temperature/Ageing

Damages by either a strong overheating, high above the acceptable permanent temperature limit what leads to a surface damaging (crack formation in general), or by a brittleness combined with a permanent deformation for an application within the polymers' temperature limits due to a too long operating time (polymer doesn't fit the application, e.g. NBR in hot water) or the usage of a not state-of-the-art recipe (sulfur cured EPDM instead of peroxide cured EPDM). This class also implies damage mechanisms that lead to an early failure due to damages on the network-structure of the material. These are different types of ageing, caused by e.g. a static deformation combined with ozone (at pre-assembled NBR-O-rings in general) or by the presence of heavy metal ions (e.g. at EPDM O-rings in hot water systems).

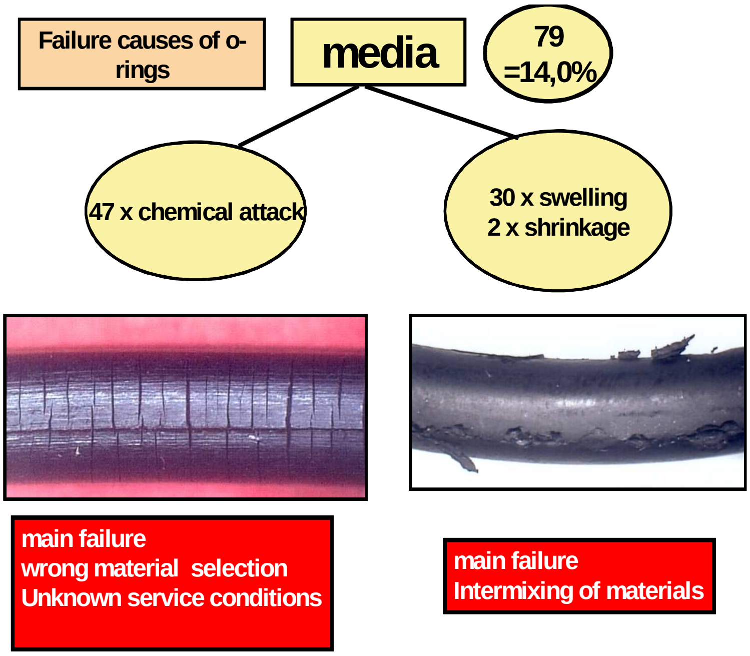

Figure 3 – unacceptable contact with media

Mechanical/Physical effects

This class includes all failure causes that are able to explain the failure without any changes in the network structure of the material but doesn't imply any manufacturing defects. The word mechanical should highlight that this class also contains damages that occur during assembly. Additional typical causes are sharp-edged clearances ore a too high deformation, gap extrusion, abrasion or explosive decompression.

Manufacturing defects

Manufacturing defects are defects that result from the manufacturing process and represent an unacceptable deviation from the target state. As far as form and surface deviations are concerned, the acceptable error range is clearly regulated by ISO 3601/part 3. Thereby, radial flowmarks and incipient cracks are the most common defects to appear. Undercuring is a serious manufacturing defect too, binding specifications for finished parts, however, do only exist in some special cases. Therefor, there are no nominal values in most cases, and even if those values exist it can be very hard to prove an undercuring after failure.

Evaluating the frequency of the different failure causes

566 failure analyses of O-ring seals result in a distribution according to **Fig.2**, regarding the different failure causes described above. It should be mentioned that in some cases a combination of different causes lead to a failure. Those failures were classified regarding the dominating failure cause. Furthermore, it should be clear that indications are being analyzed, as no “eyewitnesses” are existant.As a result it may happen that in some particular cases, despite of all acurateness and a common belief in ones own competences, indications aren’t evalueted correctly, especially if there is a lack of information concerning the failure conditions. It is remarkable that the distribution of failure causes after 110 (1st evaluation) and after 180 (2nd evaluation) failure analyses, was almost similar to the distribution after 566 analyses (**Fig.2**). This fact can be seen as an indicator for a good representation of reality.

Damage causes and symptoms caused by surrounding media

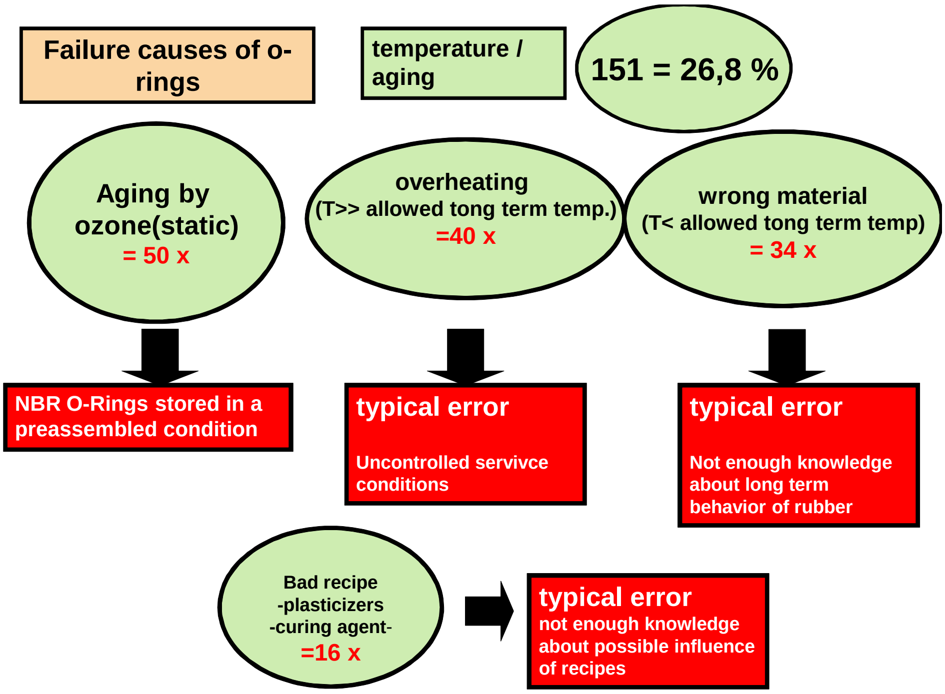

Figure 4 – failure causes due to ageing (heat and oxygen)

An unacceptable contact with media causes either a destruction of the materials’ network structure (= chemical attack) or an unacceptable swelling (**Fig.3**). While unknown operating conditions or a wrong material selection are common reasons for a chemical attack, a swelling is often caused by a confusion between different materials due to carelessness in the storage or handling of O-rings (EPDM O-rings may come in contact with oil). A common mistake concerning chemical attacks is the usage of standard FKM recipes (Co-polymer, bisphenolic cured) in cooling water applications due to the common belief that FKM-materials are a general “problem solver” as far as O-rings are concerned. Additionally, the application of chemical aggressive cleaning and sterilization media in sterile process engineering is underrated regularly.

Figure 5 – failure cause: ozone cracks

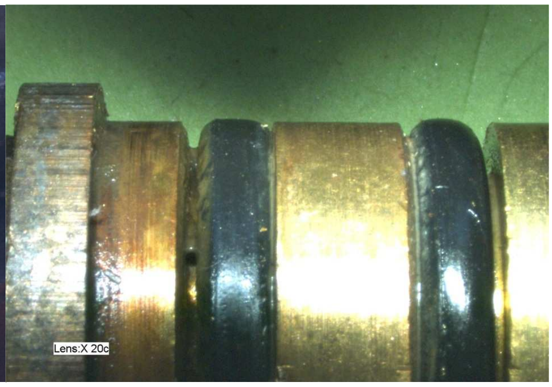

Figure 6 – failure cause: permanent deformation/brittleing

Damage causes and symptoms caused by temperature/ageing

Ageing is defined as a change in the chemical and/or physical properties of a material during storage or usage. This evaluation doesn't include the influence of the sealed media; therefor the failure causes summarized in this group are reduced to the effects of heat and oxygen (**Fig. 4**).

Fig.5 shows the damage symptoms of a failure due to "ozone cracks". Ozone cracks occur frequently at pre-assembled NBR O-rings that are exposed to ozoniferous ambient air without protection over a long period of time (at least several days).

Fig.6 shows the damage symptoms of damaged NBR O-rings. The failure occured after 1-2 years due to embrittlement and a permanent deformationat at temperatures less than 80° C in a hot water application. As the user expects a minimum life-time of 5 to 10 years, peroxide cured EPDM O-rings would have been the right choice for this application.

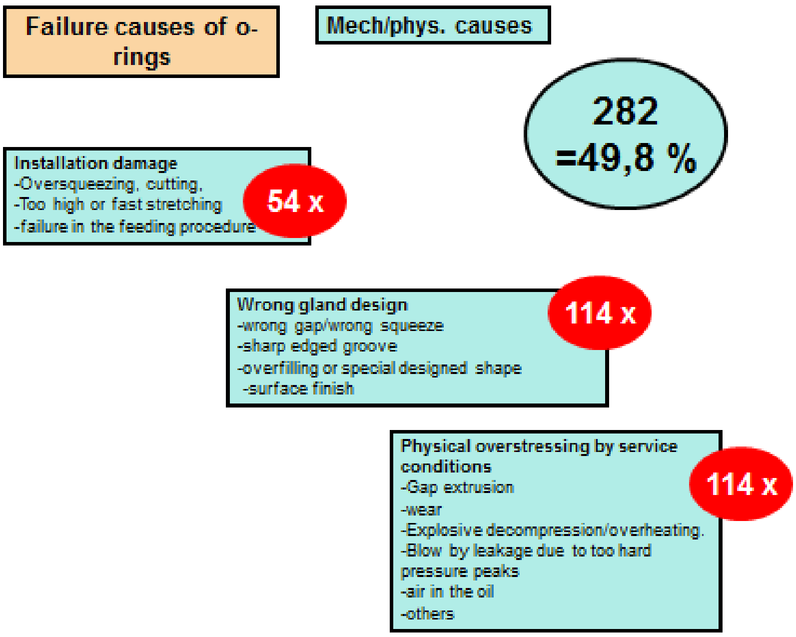

Figure 7 – Failure causes due to physical/mechanical effects

Damage causes and symptoms caused by mechanical/physical effects

This group summarizes all failure causes that are able to give an explanation of the failure without any changes in the network structure of the material but doesn't imply any manufacturing defects. A remarkable fact, regarding **Fig.7** is that a lot of failures dont occur due to common causes like gap extrusion, abrasion or explosive decompression, in fact a lot of O-rings fail due to less spectecular reasons like assembly faults or wrong clearance design.
This verifies the fact that a majority of design engineers doesnt pay enough attention to the design and the dimensioning of O-ring seals. Therefore, there is a need for action, in particular to qualify and sensitize the design and production engineers to this topic, in order to attach higher value to the field of O-ring seals.
Fig. 8 and 9 show typical examples of assembly faults that usually occur due to a bad design of the inlet and/or a lack of lubrication. Surprisingly high, namely 20.1%, is the rate of failures due to bad design and dimensioning of the clearance. That implies sharp edges, less or too much deformation, an overfilling of the clearance, clearance of diameter or poor surface quality (**Fig.10**). Only after that failure causes like gap extrusion, abrasion (**Fig.11**) and explosive decompression/explosive overheating come into play. Less well-known failure causes like dynamic caused overflowing (blow-by effect) or air in the oil [E1] are worth a mentioning too.

Figure 8 – installation damage

Figure 9 – installation damage

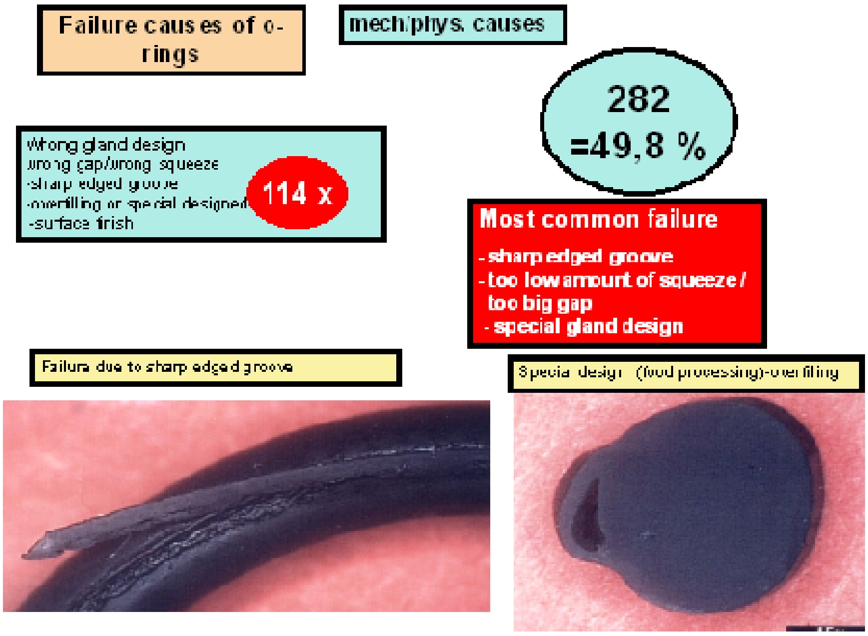

Figure 10 – failure cause: wrong gland design

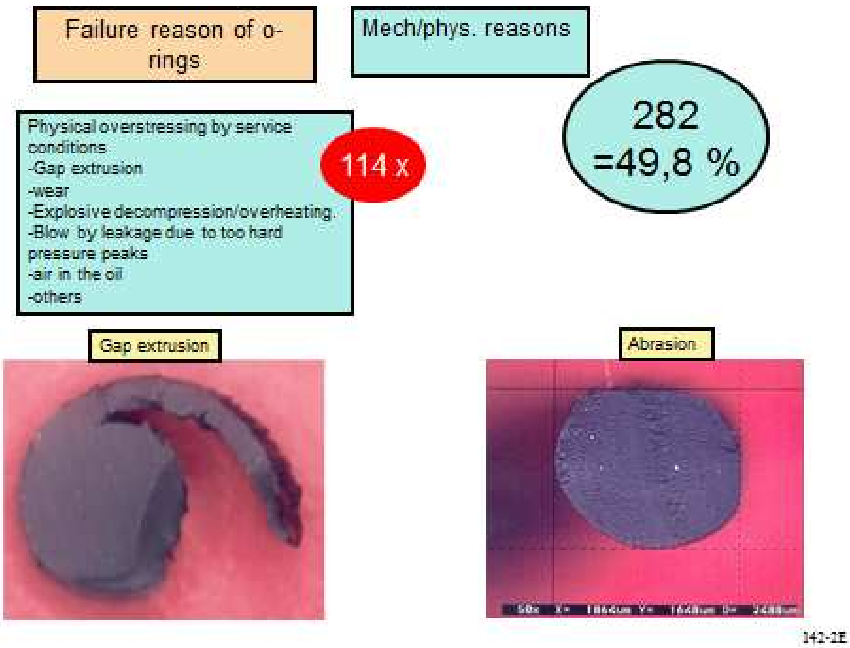

Figure 11 – failure cause: gap extrusion and abrasion

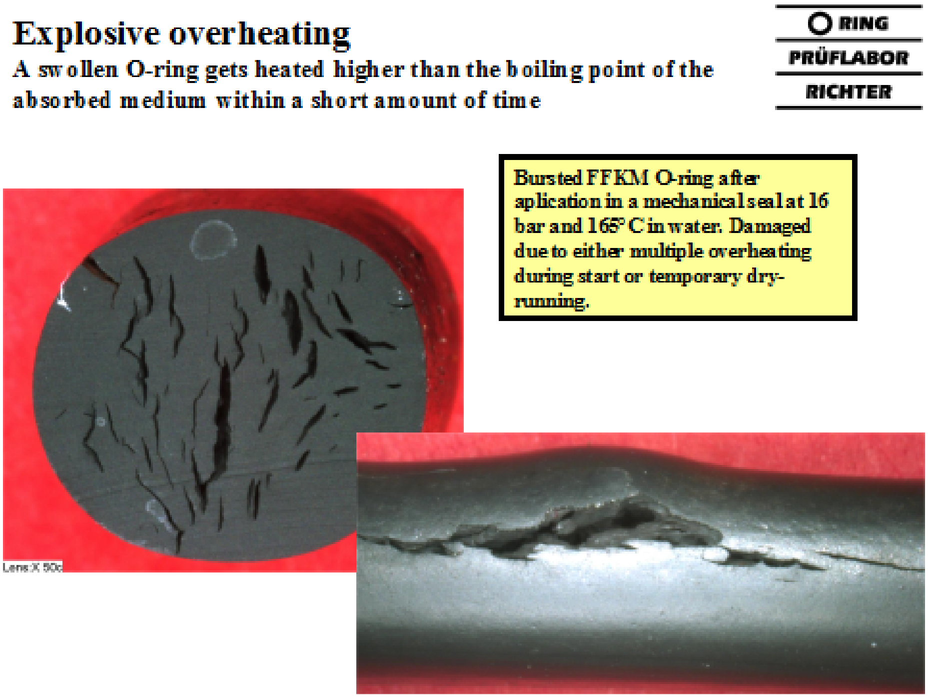

Figure 12 – failure cause: explosive decrompression

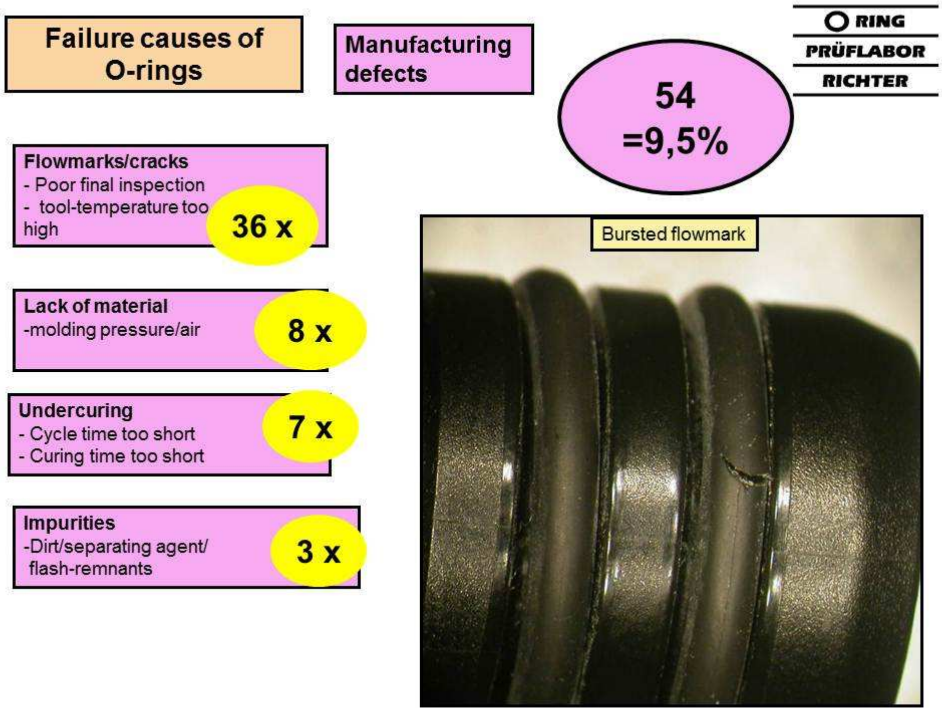

Figure 13 – manufacturing defect

Damage symptoms of manufacturing defects

Manufacturing defects are defects that develop during the manufacturing process of the O-rings (**Fig.13**). Thereby, peroxide cured EPDM and FKM O-ring show a high sensibility to flow-marks due to their bad processability, however this fact is not always considered during

manufacturing process and final inspection. And due to assembly stress, a harmless looking flow-mark may result in a deep crack and thereby lead to a leakage.
For the manufacturer, it is always associated with significant costs to sort out every damaged part, and users are not always willing to pay that extra money. This results in a reduction of the costs for the final inspection and increases the risk of failures.

Summary

This evaluation reveals the true causes of O-ring failures. Regarding the 10 most common causes, it becomes obvious that one could prevent most of the failures by a proper gland design and a reasonable choice of both, sealing material and supplier. The additional costs for those actions equal only a fraction of the costs that come along with any O-ring failure. Neither the procurement costs nor the costs for the professional qualification of the staff in the design- manufacturing- or quality assurance department but the costs for early failures will make an O-ring seals expensive.

Literature

[E1] Ebertshäuser, H.: Dichtungen in der Fluidtechnik, Resch Verlag, 1987
[J1] Jongbloed, H.: Die Dichtwirkung statischer Dichtsysteme bei dynamische Beanspruchung, 11. Internationale Dichtungstagung, 1999, Dresden
[R1] Römpp Chemie Lexikon