EXPERT KNOWLEDGE

O-RINGS

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TESTING CONSULTING DEVELOPING

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Quality Assurance on O-Rings - How is This Possible?

Important Information on the Theory and Practice of Hardness Test and Compression Set on O-Rings
(Long Version)

On the website of the O-Ring Prüflabor Richter there is also a short version of this article, which gives the reader a faster general overview of the topic. However, the short version provides less background information for a deeper understanding of the test methods described.

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The O-ring, formerly also known as a cord ring, round ring or zero ring, is a sealing element that has become indispensable in today's technology.
This sealing element is almost as old as the rubber vulcanization patented in 1845. Already in 1848, the British Alonzo Buonaparte Woodcock was granted a patent for an O-ring in a dynamic application[1]. However, it still took almost 100 years for the O-ring to make its triumphal march in technology on a broad scale. Only the experiments and patents for dynamic O-ring

[1] GB-Patent No. 12,253 vom 22. Februar 1848, Erfinder: Alonzo B. Woodcock: Steam Engines, and Apparatus for Raising and Forcing Water, &c.

applications of the Danish-American Niels Christensen[2] [3] [4] and the ever-progressing precision and quality improvement in O-ring production and the introduction of various synthetic rubber materials made it successful to this day.
For the user of O-rings, the question arises as to how he or she can check and ensure the quality of these inconspicuous sealing elements with reasonable effort.
An important advantage of O-rings is that many important physical test methods can be carried out directly on them, such as hardness and compression set tests or tensile tests on new and thermally aged O-ring seals or those stored in mediums.
With ISO 3601-5 (2015-04-01)[5], for the first time an internationally valid standard is available to the user, which specifies material properties for various elastomer materials, both on test plates and - this is the special aspect - on the finished product O-ring, which correspond to a good state of the art.
In the following, the test methods for hardness and compression set, which are frequently carried out by users, will be examined in more detail.

1. What is the Typical Testing Practice?

Supplier-customer relations in many companies are becoming more unstable due to international procurement and the immense price pressure, while the tolerance of end customers for seal failures is also decreasing. Therefore, users are well advised to specify O-rings and other seals in a sensible manner and to ensure compliance of the specifications through qualification and incoming goods inspections.
Many companies carry out at least one simplified identity test, which includes the density testing (protection against possible material confusion) and the hardness testing.
In addition to compression set tests, tensile tests or short-term storage and swelling of O-rings can also be useful as qualification tests.
In companies with high-quality laboratory equipment, infrared spectroscopic examinations and DSC measurements are also used to check the glass transition temperature as qualification and identity tests. Since incoming inspections also involve costs, the scope and frequency of inspections should also depend on how critical the respective applications are, meaning what damage a faulty O-ring lot would cause, and how difficult the manufacturing process is (see below), indicating the likelihood of critical quality deviations. Supplier-related statistical evaluations of quality deviations can also help to define meaningful inspection intervals.

[2] US-Patent No. 2,115,383 vom 26. April 1938, Erfinder: Niels Christensen: Hydraulic Brake
[3] US-Patent No. 2,180,795 vom 21. November 1939, Erfinder: Niels Christensen: Packing
[4] US-Patent No. 2,394,364 vom 5. Februar 1946 Erfinder: Niels Christensen: Pressure Seal
[5] ISO 3601-5, Second Edition 2015-04-01: Fluid power systems — O-rings — Part 5: Suitability of elastomeric materials for industrial applications

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2. What do Important Standards Say About O-Ring Testing?

Usually test standards with test specifications refer to standard specimens which are manufactured from test plates in order to determine material characteristics as reproducibly as possible. Every seal manufacturer ensures the highest quality in the manufacture of test plates so that the best compound properties can be measured. However, finished parts are vulcanized differently and their degree of cross-linking is not defined or guaranteed by data sheets.

The standardization in the "O-ring country" USA was groundbreaking for the finished part testing of O-rings. The first edition of ASTM D 1414 (current edition 2015) was published as early as 1956. It describes how to perform tensile tests, hardness and density tests, medium inclusions, aging, and compression sets on O-rings, but does not specify target values.

ISO 3601-5 (2015-04) (Suitability of elastomeric materials for industrial applications) does not focus on test methods, but on materials for O-rings and their suitability for industrial applications. The test methods used to check the nominal values required in this standard refer to ASTM D 1414 described above and other standards such as ISO 48 (hardness) or ISO 815-1 (compression set).

3. Possible Causes for Poor and/or Fluctuating Qualities of O-Rings

Depending on the polymer type, different crosslinking systems can be used, which demand different process control requirements in production. For example, fluctuations in the degree of crosslinking of sulfur-crosslinked materials (e.g. NBR, EPDM, CR) can be compensated by subsequent tempering, whereas fluctuations in peroxidically crosslinked NBR, HNBR and EPDM materials cannot be compensated or can only be compensated to a limited extent because they are not sufficiently temperature-resistant for effective post-curing by tempering.
There are also **NBR** grades in the hardness range of 70 ShA with up to 20% plasticizers by weight. Such types tend to shrink during application, as the plasticizer can be washed out by hydraulic or paraffinic oil, for example.
While NBR elastomers in O-rings are predominantly sulfur-crosslinked, **EPDM** materials are predominantly characterized by a peroxide crosslinking system, since sulfur crosslinking considerably limits the service temperature of EPDM O-rings. Since EPDM can swell with mineral plasticizers, (and even up to 50% oil-stretched EPDM polymer types can be obtained) the finished compound of such a polymer can contain up to 30% by weight of plasticizer at 70 ShA. Such compounds show a high long-term settling behavior (recognizable by compression set). They can also shrink as the oil can be dissolved by silicone oil (e.g. in sanitary applications) or hot water and evaporate due to heat. In addition, a compound with a high plasticizer content in combination with peroxides is more difficult to vulcanize since the effect of the peroxides is partially neutralized by plasticizers. Furthermore, with peroxide crosslinked EPDM, an insufficient degree of curing, as with NBR, cannot be improved by post-tempering, see above. Vulcanization must therefore take place completely in the mold during processing. A reduction in the cycle time for economic reasons can result in a high loss of quality.

Inadequate cross-linking can be proven very well with a compression set test. The primary purpose of compression set tests on O-rings is therefore not to identify the material properties of the formulation but to assess the manufacturing process of the supplier. Helpful guide values for O-rings made from peroxide cross-linked EPDM can be found in the requirements of ISO 3601-5, which also differentiates between the cross-linking systems in its target value specifications.
Fluororubbers (FKM) are mostly cross-linked bisphenolically. With regard to the degree of crosslinking, there are hardly any problems here. Moreover, the formulation of FKM compounds is much simpler (e.g. no use of plasticizers), so that the application of this material is much less critical than with EPDM. However, it should be noted that under high physical stresses, for example in the form of high pressures or abrasive stress and also in the case of long-term behavior at high temperatures, differences due to formulation and processing may very well be important.
With silicones **(VMQ)** there are often quality problems due to hardness fluctuations. These can be caused by post-processing O-rings (Mullins effect). Here it should be checked if this can have a negative effect on the application. Apart from this, VMQ materials are less critical elastomers for O-rings.

4. Hardness Test on O-Rings

Elastomer materials are generally classified and sold in five Shore A hardness steps. The Shore A hardness (ISO 7619-1, ISO 868, ASTM D2240) as material parameter refers to test plates, preferably with a thickness of 6 mm. If, on the other hand, the hardness is to be defined directly on O-rings, an additional test requirement or nominal value specification is required. Experience has shown that for O-rings with a cord thickness of approx. 3 mm or more, the material characteristic value of the formulation can be used as the nominal value (+/-5). Common for O-rings, however, is the IRHD microhardness according to ISO 48 (sub-process **CM** ("**C**urved surface"), "**M**icro"(indenter)). This hardness testing method is adapted to the Shore A method in such a way that the nominal value of the hardness of the material for O-rings from a cord thickness of 1.6 mm can also be used as the IRHD-CM nominal value (+/-5). For smaller cord thicknesses, it is common practice (ISO 3601-5) to extend the nominal value tolerance range to +5/-8 IRHD-CM degrees of hardness. For many users, hardness testing is the only material test that is carried out in addition to an optical and dimensional check. Accordingly, this parameter is highly evaluated and overrated. Conclusions are drawn from the hardness test which it cannot provide or can only insufficiently provide. For instance, the hardness measurement can only give vague information about the degree of cross-linking of a gasket.
The hardness provides an indication of the deformation behavior of elastomers and their ability to compensate roughness in the sealing surface or to withstand gap extrusion. The hardness does not say much about the stiffness of the material.
The measurement system analysis of the hardness test is often overestimated. In comparison with other physical elastomer testing methods, it performs significantly worse. Furthermore, the digital displays of hardness testers tempt the user to state the hardness values with decimal places. This, however, is not reasonable.

"The hardness is often also measured on pre-aged samples, e.g. after hot-air contact. Since hot-air aging occurs first and also most strongly in the outer layers of an elastomer, hardness measurement is a useful method for showing small changes in the surface layers. However, the IRHD-M test method will be preferable to the ShA test method due to the lower penetration depth and higher precision." [6]

4.1 Useful Influencing Factors on the Hardness Testing of O-Rings

In the IRHD microhardness test, a ball (= indenter) with a diameter of 0.4 mm and a defined weight penetrates into the specimen. The penetration depth is a measurement of the hardness. The indenter should contact the highest point of the O-ring cross-section. Due to the curved surface, the indenter ball can penetrate more easily than a flat or concave surface because it has to displace less material. Since a large penetration depth indicates a soft material, O-rings appear to be less hard than comparable test plates.

This problem is also addressed by DIN ISO 48, which introduces its own procedure designations for the measurement of curved surfaces and speaks of "apparent hardness", "since these tests are usually performed on complete finished parts where elastomer thickness may vary and the lateral dimensions may not in many cases allow the minimum distance between the indenter and the side edge to be maintained, which can cause edge effects. Therefore, the results obtained are generally inconsistent with those obtained on standardized specimens as defined in methods N, H, L or M (...)"[7]. For O-rings, the CM sub-process is usually used. For this reason, it is very important to determine with the supplier not only a hardness value for the test plates, but also for the finished O-rings.

In literature there are formulas for estimating the real hardness[8] [9], which allow a deeper understanding of the problem and can serve as orientation but are of little importance for the practitioner in the application.

In order to measure exactly and reproducibly at the uppermost point of the O-ring cross-section, a centering device, or even better, a laser-guided table (see **Fig. 1 and 2**) should be used, especially for small cord thicknesses (e.g. < 2.62 mm).

[6] Translated form BLOBNER, U.: Fachwissen Prüfverfahren für Elastomere: 1915 – 2015: 100 Jahre Shore A – Härteprüfung Ein historischer Rückblick auf Entwicklung und Forschung zur Shore A – Messmethode mit Bezug zur heutigen Prüfpraxis, Internetveröffentlichung, 12/2015, S.35 (http://www.o-ring-prueflabor.de/files/fachwissen-100_-jahre_-shorea-12_2015.pdf), S.37
[7] DIN ISO 48: Elastomere oder thermoplastische Elastomere – Bestimmung der Härte (Härte zwischen 10 IRHD und 100 IRHD) (ISO 48:2010), Ausgabe September 2016, S. 8
[8] ACHENBACH, M. und STREIT, G.: Härtemessungen an O-Ringen – Abhängigkeit der Härte von der Schnurstärke und dem Innendurchmesser in: KGK, 42. Jg., Nr. 10, 1989, S. 892-897
[9] PARKER HANNIFIN GmbH: Dichtungshandbuch, Bietigheim-Bissingen, 1999, S.61

Fig. 1: Stationary IRHD micro-tester with laser-guided table for exact hardness measurement of O-rings (CM method)

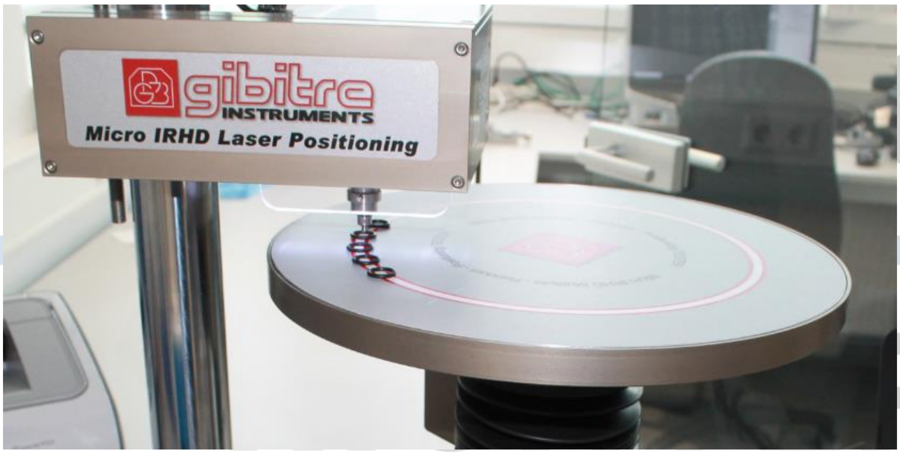

Fig. 2: Laser-guided rotating table for automated IRHD-CM measurement of a larger number of O-rings

An important advantage regarding the precision of the IRHD method is that these test instruments are only available as floor-standing instruments and not, as in Shore A measurement, as table-top and parallel analog hand-held instruments. With the latter, a large influence of the operator is possible.

In addition, the test temperature (23°C) should be within the prescribed tolerance (±2K), since elastomers are strongly temperature-dependent.

For the sake of completeness, three other influential factors should also be mentioned, which, however, can be neglected in day-to-day operations:

Post-processing of O-rings can lead to slight deviations in hardness. "Surfaces that have been ground or otherwise prepared (...) can lead to hardness values that differ slightly from those obtained on surfaces with a smooth vulcanizing skin"[10] (compare Mullins-effect with VMQ).
The coating of an O-ring reduces friction and improves the penetration of the indenter, which can minimally alter the test result.
"For certain plastics, such as polyamide, the serious influence of moisture content on various material properties, such as tensile strength or hardness, is generally known. There are similar effects with elastomers, but less pronounced than with polyamide. Of particular note, here are mostly colored compounds with hydrophilic and mineral fillers, such as various FKM compounds. Pre-drying for a few hours can reveal considerable differences in strength in the tensile test.[11] For hardness, this influence is smaller and disappears in the random measurement uncertainty."[12]

The possible deviations of up to 10 IRHD degrees between finished parts and the normal hardness[13] described in ISO 48 do not correspond to the experience of our many years of testing practice!

Hardness measurement on O-rings is recommended but should be combined with other methods such as density and compression set testing. This is the only way to obtain reliable information on formulation identification and the quality of an O-ring.

5. Compression Set Test on O-Rings

ISO 3601-5 requires ISO 815-1 (Method A) as the test method to be used for the compression set. However, since ISO 815-1 deals exclusively with the testing of standard specimens, the special features of compression set testing on O-rings should be dealt with here.
In the compression set test, an elastomer component is usually compressed by 25% and then stored at an elevated temperature. Typical test times are 24^{-2} and 72^{-2} hours. After removal from the oven and removal of the compression, the height difference of the component is determined from the measurement before and after the test and related to the deformation height. The more a gasket has "settled", the higher and worse the compression set result [%] of this gasket.

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[10] DIN ISO 48: Elastomere oder thermoplastische Elastomere – Bestimmung der Härte (Härte zwischen 10 IRHD und 100 IRHD) (ISO 48:2010), Ausgabe September 2016, S. 8

[11] BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Zugversuch - Prüftechnische Grundlagen und Empfehlungen für die praktische Anwendung, Internetveröffentlichung, 10/2014, S.23 (http://www.o-ring-prueflabor.de/files/fachwissen-zugversuch_10_2014.pdf)

[12] Translated from BLOBNER, U.: Fachwissen Prüfverfahren für Elastomere: 1915 – 2015: 100 Jahre Shore A – Härteprüfung Ein historischer Rückblick auf Entwicklung und Forschung zur Shore A – Messmethode mit Bezug zur heutigen Prüfpraxis, Internetveröffentlichung, 12/2015, S.35 (http://www.o-ring-prueflabor.de/files/fachwissen-100_-jahre_-shorea-12_2015.pdf)

[13] DIN ISO 48: Elastomers or thermoplastic elastomers - Determination of hardness (hardness between 10 IRHD and 100 IRHD) (ISO 48:2010), September 2016 edition, p. 8: "Therefore, the results obtained on curved surfaces are random values which apply only to specimens or finished parts which have a specific shape and dimensions and which are held in a specific manner. In extreme cases, results may deviate from normal hardness up to 10 IRHD".

Fig.3: Compression set test tools with base plate ground to different depths (see lower plate), the use of spacers is not necessary.

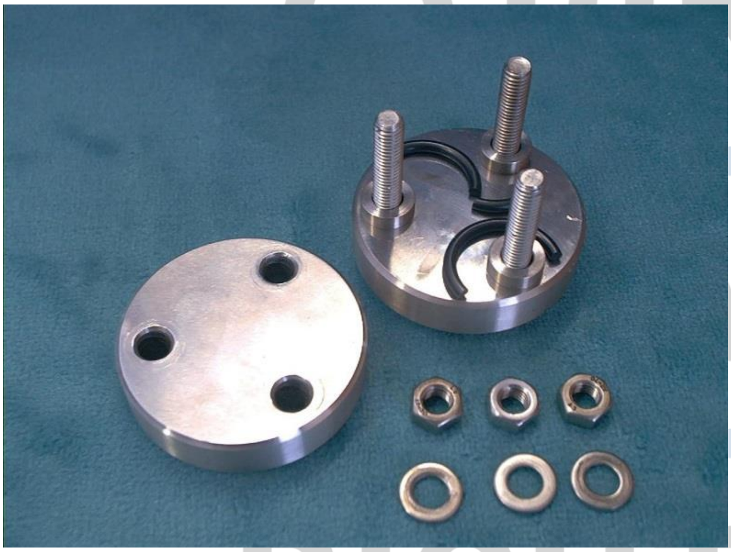

Fig. 4: Flat plates for compression set measurement with spacers: there are three O-ring sections on the base plate which can be identified by the different lengths. Due to the round shape of the tool, it can also be stored in liquid mediums in the beaker.

"The greatest practical significance of compression set testing can be found in the testing of finished parts, especially O-rings (see **Fig. 4**). The purpose here is not to determine the formulation-specific characteristic value as found in material data sheets, but to be able to provide information about the degree of vulcanization of the finished part."[14]

However, the compression set hardly provides any information about the viscoelastic properties of the material. If the compression set value is not more than 10-30% above the formulation-specific characteristic value for 24^{-2} h (test temperature = permissible 1000h continuous temperature), an acceptable degree of vulcanization can still be assumed.

[14] BLOBNER, U. und RICHTER, B.: Druckverformungsrestprüfung (DVR-Prüfung): - Prüftechnische Grundlagen und Empfehlungen für die praktische Anwendung, Internetveröffentlichung, 06/2015, S.4 (http://www.o-ring-prueflabor.de/files/fachwissen_druckverformungsrestpruefung_06_2015.pdf.pdf)

Orientation values for a finished part specification (general industrial standard or good state of the art) can be found in ISO standard 3601-5[15] (2015-04-01)".[16]

A test method competing with the compression set on O-rings is the tensile set. O-rings are stretched over a mandrel and then stored at elevated temperature for a certain period of time. After removal from the oven and removal of the strain, the length difference of the component is determined from the measurement before and after the test and related to the deformed length.
The tensile set test is carried out almost exclusively on finished parts (especially O-rings). Particularly with small cord thicknesses, this test method provides a lower measurement uncertainty than the compression set. In addition, the test tool (mandrel) for the tensile set is easier to manufacture than plane-parallel plates for the compression set test method. The disadvantage is that a non-contact measuring machine is required for the final measurement after the test in order to obtain exact results. This is not always available in smaller companies. The compression set test only requires a simple height measuring device for the final measurement.
The new industrial standard ISO 3601-5 only requires compression set values and no tensile set values. Both methods provide similar results.

5.1 Useful Factors Influencing Compression Set Testing of O-Rings[17]

The cord strength of O-rings has an important influence on the compression set result.
In the case of good processing, or vulcanization, this can hardly be seen in the short-term test (22^{+2}h) (see **Table 1**, NBR formulation 1), as long as the test temperature is not higher than the permissible long-term temperature of the material (1000h criterion). However, longer test durations (70h) indicate a tendency towards better, lower compression set values. Here the influence of geometry increases if the test takes place at the long-term temperature or higher.
In the case of the less well processed formulation 2, the O-ring with the lowest cord thickness has the best compression set value after 22^{+2}h. Consequently, due to its smaller volume, it was better vulcanized than the two thicker O-rings. The 70h results again show more of the geometric influence, the strong processing influences are no longer correctly recognizable here.
Thousands of compression set tests carried out in the O-Ring Prüflabor Richter have shown that at 24h test time and at an appropriate test temperature (= permissible continuous temperature) the influence of the cord thickness is not greater than other random influences

[15] ISO 3601-5, Second Edition 2015-04-01: Fluid power systems - O-rings - Part 5: Suitability of elastomeric materials for industrial applications, S. 3, Table 2: O-ring requirements
On page 3 of ISO 3601-5 (Second Edition 2015-04-01), the layout was incorrectly moved to "Table 2". In the second line, the hardness values were assigned to incorrect base polymers. Correctly, the hardness classes (IRHD) 70, 75, 80, 90 belong to FKM, only 70 to VMQ, 70 to EPDM-S 70 and 80, 70 and 80 to EPDM-P and 70 to ACM. There were no shifts in the lines below, so that the table can still be used after correction of the assignment. The error will be corrected soon.
[16] Translated from BLOBNER, U. und RICHTER, B.: Druckverformungsrestprüfung (DVR-Prüfung): - Prüftechnische Grundlagen und Empfehlungen für die praktische Anwendung, Internetveröffentlichung, 06/2015, S.4 (http://www.o-ring-prueflabor.de/files/fachwissen_druckverformungsrestpruefung_06_2015.pdf.pdf)
[17] Ausführliche Informationen zu den Einflussfaktoren: Siehe: Ebd., S. 15-21 (http://www.o-ring-prueflabor.de/files/fachwissen_druckverformungsrestpruefung_06_2015.pdf.pdf)

(measurement uncertainty during height measurement, planarity of the test tool plates (see **Fig. 3**), temperature and time fluctuations).

	NBR (Composition 1)			NBR (Composition 2)		
Cord Thickness [mm]	1.78	3.53	6.99	1.78	3.53	6.99
Compr. Set After 22+2h, at 100°C [%]	10	13	9	11	16	18
Compr. Set After 70+2h, at 100°C [%]	24	23	17	24	24	29

Tab. 1: Influence of cord thickness on compression set (source: O-Ring Prüflabor Richter)

During the compression set test, O-rings should be compressed with 25% if possible, so that comparability with other compression set tests is better. At higher compressions (up to approx. 40%) the compression set value usually improves, at lower compressions it deteriorates.

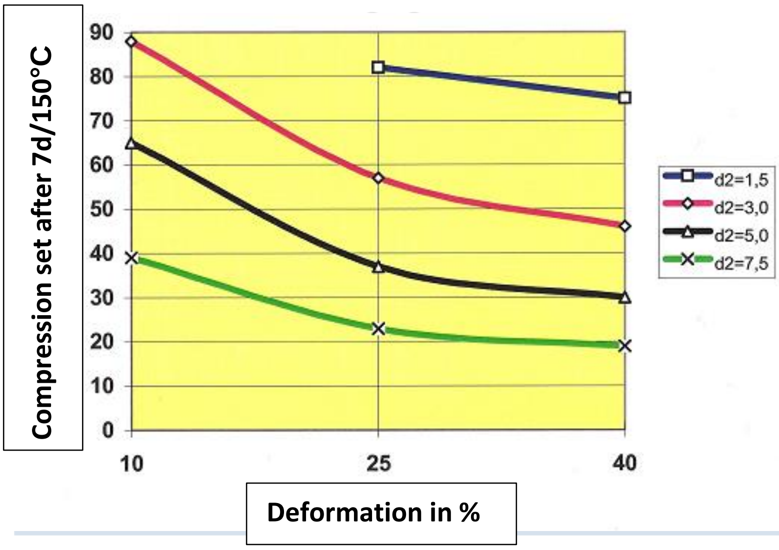

Fig. 5: Influence of deformation / compression and cord thickness on the compression set of O-rings, determined on an HNBR sample formulation, compression set results after 7 days (= 168h) at 150°C [18]

The stress relieving temperature of the specimens after removal from the oven also has a major influence on the result. ISO 815-1 offers three methods, A, B and C, whereby the first two occur most frequently in practice. In method A, which is also required in ISO 3601-5, the stress is released immediately after removal from the oven, which alone shows the influence of aging. In method B, the test specimen is cooled to room temperature after removal from the furnace in the tense state, whereby it additionally contains a reversible permanent deformation (physical relaxation). The latter process rather reflects the application, process A directly indicates the quality of the vulcanization. For this reason, method A is usually used in incoming goods inspections.

[18] MAGG, H., Bayer AG, Seminar „O-Ringe in Kraftfahrzeugen“ am 07.10.1997 im Haus der Technik, Essen

As already indicated with the geometry-related influences, the processing has a significant influence on the compression set results.

"The following processing study (**Tab. 2 and 3**) [19], which was determined on peroxidic cross-linked HNBR O-rings, shows on one hand the high sensitivity of the compression set value to too low tool temperatures (**Tab. 2**). On the other hand, these diagrams prove that a strong under-crosslinking of O-rings (T = 170 °C) cannot be proven by hardness measurement (**Tab. 3**) since the production-related scattering of the hardness values are almost always within a range of 10 hardness points. The resolution or sensitivity of the compression set measurement is much higher than that of the hardness test. This becomes particularly clear when considering and comparing the values with a tool temperature of 170°C. If only the hardness values are considered, a clear increase can be noticed. At first glance, one could assume that this is a sign of the improving degree of crosslinking. However, if one compares the compression set results at 170°C, it is surprising to note that compression set values of 100% or greater are achieved at all three cycle times, which is a clear sign of undercure and would in practice lead to significantly premature failure.

Tool Temperature	Compression Set After Cycle Period of 60sec.	Compression Set After Cycle Period of 120 sec.	Compression Set After Cycle Period of 180 sec.
170°C	108%	103%	100%
190°C	95%	75%	47%
210°C	39%	35%	30%

Table 2: Influence of the processing parameters on the compression set (24h at 150°C) on a HNBR O-ring with the dimensions 19.3mm x 2.4mm (source of data: Parker Hannifin GmbH)

Tool Temperature	Hardness After Cycle Period of 60 sec.	Hardness After Cycle Period of 120 sec.	Hardness After Cycle Period of 180 sec.
170°C	58 IRHD	63 IRHD	66 IRHD
190°C	64 IRHD	68 IRHD	71 IRHD
210°C	67 IRHD	69 IRHD	69 IRHD

Table 3: Influence of processing parameters on hardness (24h at 150°C) on a HNBR O-ring with the dimensions 19.3mm x 2.4mm (Source of data: Parker Hannifin GmbH)"[20]

[19] RICHTER, Bernhard: Vortrag „Dichtungswerkstoffe für O-Ringe“ im Seminar "Anwendung und Instandhaltung von Gleitringdichtungen" am 29./30.November 1995 im Haus der Technik, Essen

[20] BLOBNER, U. und RICHTER, B.: Druckverformungsrestprüfung (DVR-Prüfung): - Prüftechnische Grundlagen und Empfehlungen für die praktische Anwendung, Internetveröffentlichung, 06/2015, S. 19f. (http://www.o-ring-

6. Conclusion

Due to ever increasing quality requirements - also for the mass-produced O-ring - it is for seal users not only sensible, but also necessary to clearly define the quality of O-rings and to control it appropriately. ISO 3601-5 provides good assistance in this respect in terms of target values and test methods.
It is most likely the most frequently performed physical test methods in incoming goods are the measurement of density[21], hardness and compression set. These test methods are considered simple and generally known. The importance and significance of compression set testing as a finished part test, on the other hand, is usually underestimated. If these test methods are implemented correctly and consistently, the user can ensure consistent quality despite global and economical procurement. However, this does not release the user from the obligation to adequately verify the basic suitability of the formulation used and to check or qualify the supplier with regard to his processing and quality competence.

A short version of this article appeared in the journal "KGK Kautschuk Gummi Kunststoffe" published by Hüthig Verlag, double issue 07/08 2018, p. 12-15. (German)

prueflabor.de/files/fachwissen_druckverformungsrestpruefung_06_2015.pdf.pdf)

[21] Ausführliche Informationen zur Dichteprüfung: Siehe: BLOBNER, U. und RICHTER, B.: Identitätsprüfung: Übereinstimmungen finden; Internetveröffentlichung, 03/2014, (http://www.o-ring-prueflabor.de/files/fachwissen_identit__tspr__fung_03_2014.pdf)