EXPERT KNOWLEDGE
FAILURE ANALYSIS
OF ELASTOMER COMPONENTS

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TESTING CONSULTING DEVELOPING

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Thermal Overload -
Rarely Temperature is the Sole Problem, In Most Cases the Problem is the Wrong Combination of Temperature and Time

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1. Classification and Frequency of Failure

Out of the four main failure mechanisms thermal overload is classified in the second group below:

1. Media
► **2. Temperature / Aging**
3. Mechanical / Physical Damages
4. Manufacturing Errors

After evaluating over 500 failure analyses, it can be assumed that 10-15% of all sealing failures are caused by this failure mechanism.

2. Professional Background Knowledge about Damage Symptoms

Contrary to metals, polymers have much lower operation temperatures.

This is particularly obvious looking at conventional natural rubber, which should not be stressed beyond 70°C during continuous operation. Due to the comprehensive introduction and development of synthetic rubbers in technical applications for over 80 years, high temperature resistant elastomers are now also available for the practitioner; however, they come at a price. A per-fluorinated rubber compound (FFKM, heat resistance: ca. 260-300°C), for example, is up to 5000 times more expensive[1] than an SBR-rubber compound (heat resistance max. 100°C).

For plastics the maximum permissible permanent temperatures can be defined simply by their melting point. However, this definition is more difficult for elastomers because they have no melting point. If the decomposition temperature of elastomers was the minimum criterion, the permissible operating time would be very short.
For the definition of temperature limits for elastomers, therefore, one is no longer on the firm ground of clear physical limiting criteria but on shaky foundations. In general, the approach to define the temperature at which elastomers at least can be used 1000h as the permissible permanent temperature has gained acceptance for elastomeric materials. As limiting criterion for the loss of elasticity during aging through heat and oxygen (i.e. a chemical damage mechanism), the loss of 50% of the original elongation at break is set. So-called permanent temperatures for NBR-elastomers of 100°C for peroxide cross-linked EPDM elastomers of 150°C and for FKM-materials of at least 200°C are explained by this definition, though they are or were only checked exemplarily on sample formula.
The temperature dependence of chemical reactions complies with the Arrhenius equation, which simplified can be reduced to the rule that temperatures 10 K higher than these stated permanent temperatures halve the permissible operating times (1000h), whereas temperatures that are 10 K lower lead to a doubling of these stated operating times. Consequently, a thermal overload of elastomers can be described as a significant exceeding of the permissible application limits derived from temperature and time. Hence, on the one hand, relatively high temperatures are permissible for short operation times, but on the other hand, only surprisingly low temperatures are permissible for long operation times, for example 60°C for NBR-elastomers having a period of application (continuous) of ca. 2-5 years.

[1] NAGDI, Khairi: Gummi-Werkstoffe - Ein Ratgeber für Anwender, Dr. Gupta Verlag, Ratingen, ²2002, S. 105

3. Damage Symptoms

3.1 Description of Damage Symptoms and Problematical Areas (including picture examples)

Thermal overload over a long period causes the embrittlement of O-rings or seals over the whole cross section. During bending cracks are seen preferentially on the air side or on the sealing surfaces on which the application of heat took place (see **Figure 1 and 3**).
When EPDM-compounds, whose base polymer consists only of carbon and hydrogen, overheat, a sooty surface can generally be seen which, if rubbed with the finger, rubs off/smears. Seals consisting of NBR-rubber get a shiny surface after thermal overload, whereas FKM-elastomers stick together with the mostly metal mating surface.
Without the embrittlement of the seal as a whole, brief severe overheating leads to fine deep cracks (scaling or embrittlement only in the edge area, see **Figure 2**), which are only seen at pulling and bending. Due to the temporary short load and the insulating effect of the rubber material, the excessive temperature cannot yet visibly damage the inner area.

Figure 1: Thermally damaged O-Ring, fully cured, during bending cracks visible on contact surface

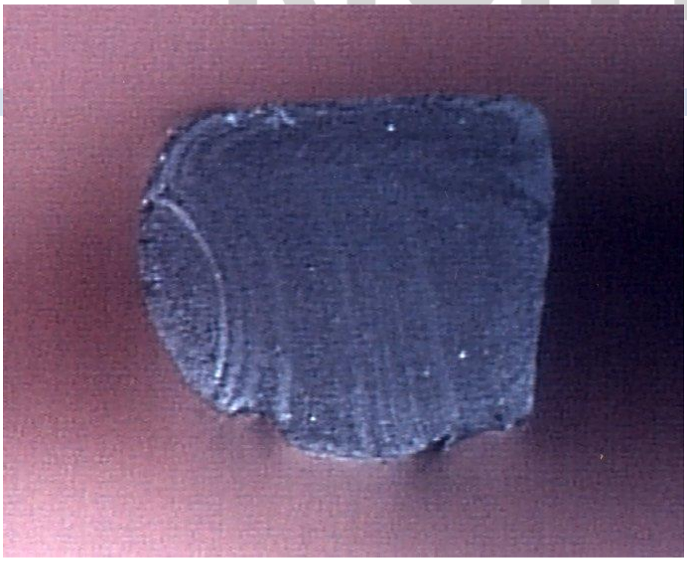

Figure 2: Cross section of severely overheated O-ring (short operating time) due to dry start-up of a slide ring seal compression set and the striking of local embrittlement, the core is still fully elastic

Figure 3: Brittle NBR O-ring shows cracks during bending (rotary scoring is an impression of the mating surface) Differentiation from ozone cracks: hardening of cracked zones. With ozone or fatigue cracking there are cracks in the still elastic elastomer matrix.

During long-term overheating – like an accelerated hot air aging - the seal is more likely damaged homogeneous. During a short-term overheating often only the area which was exposed to the excessive heat is damaged.

3.2 Effects of Damage

During severe thermal overload of short duration, the surface of the seal becomes massively brittle with the result that even small local stretching, e.g. by pressure-induced flexing work with O-rings or by micro deformation of the sealing edge of a radial shaft seal, can lead to crack formation and leakages. During a continuous thermal overload, the whole sealing cross section becomes brittle, it can no longer bend under operating conditions, and it becomes severely deformed. Thereby, it cannot follow the changing sealing gaps any longer.

3.3 Differentiation from similar Damage Symptoms

The damage symptoms of overheating are not always easily differentiated from chemical degradation. The latter cracks are preferentially found on the product side; the seal itself is often still elastic but breaks when strongly bent or pulled.

4. Preventive Measures

The following questions can help the practitioner prevent this failure:

- Are the actual temperature loads of the application known?
- Which maximum continuous service temperature has my elastomeric material?
- Are there temperature peaks? How high, how long?

- Was the overheating caused by the lack of lubricant? (e.g. overheating of a slide ring seal at the contact surfaces of the slide ring by dry start-up)
- Does an energy influx occur, e.g. by vibrations, which then leads to an inner heating?

5. Practical Tips (Testing Possibilities / Standard Recommendations)

In general, it is recommended to determine the temperature limit of a material by means of hot air aging (e.g. according to ISO 188, DIN 53508 or ASTM D573). If the maximum temperature load and the respective periods of a technical application can be assessed relatively well, i.e. temperature collectives are known, a compensational isothermal load can be determined by simplified Arrhenius multipliers. If the material is tested according to this load, a real application can be simulated very well through hot air aging in the laboratory.[2]

Experience shows that influences resulting from formula are underestimated. Even storage in hot air of 1-2 weeks or compression set tests of the same length are sufficient to show whether a good state of the art of the respective compound actually is on hand (a comparison with formula specifications of ISO 3601-5 is recommended).

Concerning very critical applications, it is recommended, if possible, to perform hot air aging on the component (e.g. O-ring). Besides the information about the material, information about its processing is obtained, which can have a lasting effect on the heat resistance of the component.

6. Miscellaneous

An abstract version of this article was published in German in the magazine "DICHT!", issue 02/2017.

[2] Further information: BLOBNER, U. und RICHTER, B.: Heißluftalterung von Elastomeren: Prüftechnische Grundlagen und wissenswerte Besonderheiten, 06/2015, http://www.o-ring-prueflabor.de/files/fachwissen_hei__luftalterung_06_2015.pdf