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Extrusion –
The Sealing Gap as Enemy of the Seal

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In literature this optically memorable cause of failure is often described. Due to increasing pressure, a seal adapts more and more to its installation space until it is finally pressed into the gap facing away from the pressure. Due to the high pressure, more and more new material is pushed into the gap, sometimes resulting in long extrusion strips. This process is known as extrusion or gap intrusion.

In this context, pressure, structural boundary conditions, sealing material and temperature are important influencing factors.

The mostly predefined pressure has the most important influence on the gap extrusion. With typical material hardnesses of 70 Shore A or higher and with the usual gap dimensions of max. 0.3 mm, the damage mechanism does not occur below 50 bar pressure. The pressure rise rate must also be taken into account. Hard or fast pressure shocks (e.g. on forklift trucks) involve a considerably higher risk than soft, meaning “slow" shocks.

The most important design condition is the sealing gap. In dynamic applications, a possible expansion of the cylinder under pressure should also be considered.

In fluid technology, a typical sealing gap (piston Ø: 20 to 100 mm) is 0.07 to 0.13 mm, e.g. in accordance with ISO 3601-2 (H8/f7).
Generally, when selecting the correct material hardness at a given pressure depending on the gap dimension the theoretically maximum possible diameter clearance should always be used as a basis. In principle, an edge radius of 0.05 to 0.1 mm corresponds to the ideal case; 0.2 ± 0.1 mm is usual. With groove recessing, the edge radius should merge with the groove flank without discontinuity.
Hardness is usually mentioned as the most important property of the sealing material, although modulus and strength are also important. Major seal manufacturers offer diagrams with which extrusion-resistant seals can be designed. Generally speaking, all sealing materials whose mechanical properties (tensile strength, elongation at break) decrease drastically at elevated temperatures are very susceptible to gap extrusion. This is why they often require support rings. Thermoplastic polyurethanes (TPU) with relatively high hardness of 92 to 96 Shore A are known for their high resistance to abrasion and extrusion.
With elastomers and TPUs, however, the load limits decrease as the temperature rises, which increases the risk of gap extrusion as the temperature rises. Swelling (>10%) or chemical degradation can also greatly reduce the load limits (see **Fig. 1**) and therefore lead to failure.

Damage Pattern and Problematic Areas

The cross-sectional image of an almost completely unrolled O-ring is very memorable and clearly identifiable (see **Fig. 2**). Such clear damage patterns are usually only caused by very sharp-edged grooves in combination with the corresponding gap and pressure. More typical and more frequent, however, is the damage pattern from **Fig. 3**.

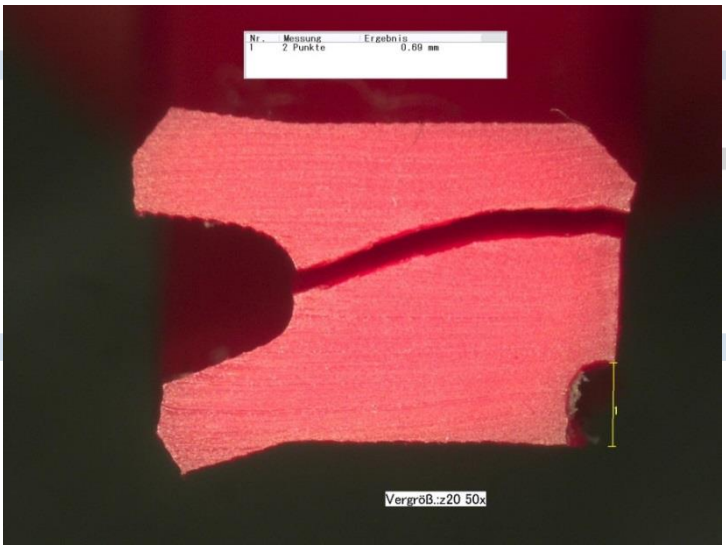

Fig. 1: Damage at the sealing gap of a hydraulic seal and subsequent rupture due to hydrolysis

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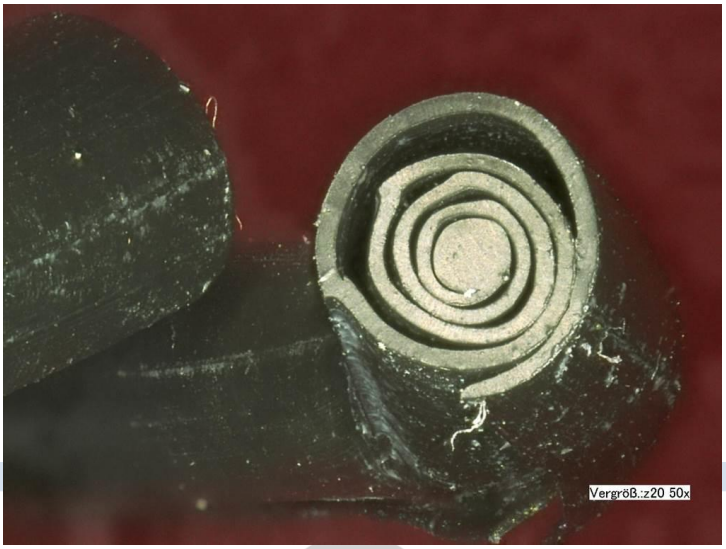

Fig. 2: Gap extrusion of an O-ring through sharp-edged groove recess (p = 350 bar, gap = 0.05 mm)

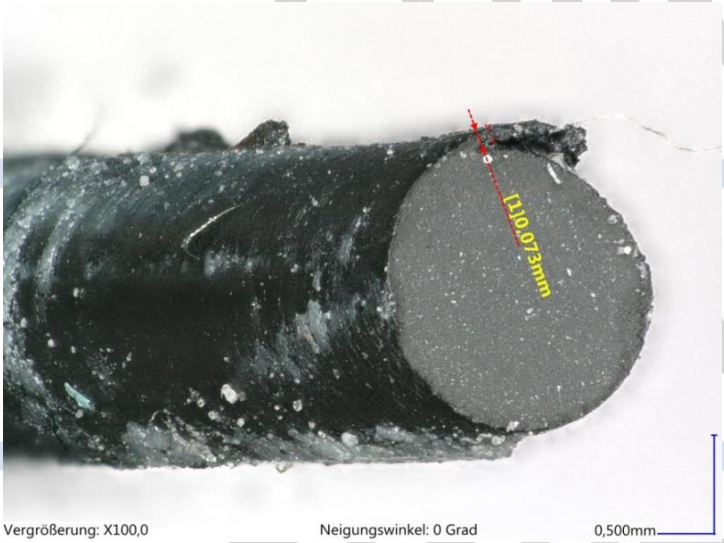

Fig. 3: Typical damage pattern of a gap extrusion

The damage occurs primarily in the areas of greatest eccentricity or greatest sealing gap. The remaining corpus of the seal is usually still fully rubber-elastic.

Differentiation from Similar Types of Damage

The damage pattern of gap extrusion can resemble the damage pattern of the assembly error (compression). It can also be confused with damage caused by expanding air or groove overfilling.

Preventative Measures

Compounds with greater hardness, higher modulus and higher strength should be preferred where possible. By using extrusion-resistant support rings, this damage pattern can be prevented in static applications, but also in slow translational or rotating movements. In addition, reducing the edge radii to 0.1 - 0.05 mm can prevent gap extrusion.

Practical Tips (Testing Possibilities / Standard Recommendations)

A very pragmatic approach is to use TPU seals in critical applications where possible. ISO 3601-4 provides the designer with helpful information on the design of support rings.