AEROSPACE INFORMATION REPORT	AIR1707	REV. B
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Patterns of O-ring Failures

RATIONALE

Document was updated for 5-year review and clearer, more legible images were included.

1. SCOPE

The information presented herein describes the commonly observed patterns of O-ring failure by means of both text and illustration. Possible causes and corrective actions are indicated for alleviating the problem.

1.1 Purpose

This document is intended to provide a guide for analyzing O-rings which have failed in order to correct the circumstances which have caused the failure. A great deal can be learned toward solving a sealing problem involving O-rings by close observation of the failed O-ring.

2. REFERENCES

There are no referenced publications specified herein.

3. FAILURE PATTERNS

3.1 General

Failures are usually due to a combination of causes. The patterns of O-ring failure described herein, then, represent the modes most often encountered. Subtle variations will occur, but the major cause generally predominates.

3.1.1 Note that this document does not advise on rubber compound selections or design details, although some general guidance comments are made. Consult an applications engineer for material selection, design details, and the proper use of antiextrusion devices. Also, consider the substitution of other sealing types for the O-ring.

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3.1.2 The failures discussed herein have been classified under the following headings:

Extrusion and Nibbling	3.2
Spiral Failure	3.3
Abrasion	3.4
Compression Set	3.5
Weather and Ozone Cracking	3.6
Heat Aging and Oxidation	3.7
Plasticizer Extraction	3.8
Installation Damage	3.9
Gas Expansion Rupture	3.10
Failure Due to Backup Ring	3.11

3.2 Extrusion and Nibbling

3.2.1 Occurrence

Usually associated with dynamic rod or piston seals but can occur in a static seal with pressure pulsations, especially where it opens and closes the clearance.

3.2.2 Appearance

Exhibits many small nibbles removed from the O-ring adjacent to the downstream clearance area, or a small section of the O-ring may be extruded. Typical of high pressure systems, this process sometimes erodes half of the O-ring cross-section before major leakage occurs.

3.2.3 Cause

Clearance is too large, pressure is too high, O-ring is too soft, O-ring is softened and swelled by fluid, clearance increases under pressure, eccentricity causes irregular gap, and corners of O-ring gland are too sharp.

3.2.4 Corrective Action

Closer metal fits (reduce diametral clearance or reduce plate gap,) use of backup rings or other antiextrusion devices such as cap strips, harder O-ring material, use of O-ring more compatible with system fluid, more rigid or concentric metal components, and break edges of gland to a radius of about 0.001 to 0.002 inch (0.025 to 0.050 mm). T-seals that fit into the same gland may also be substituted.

3.2.5 Examples

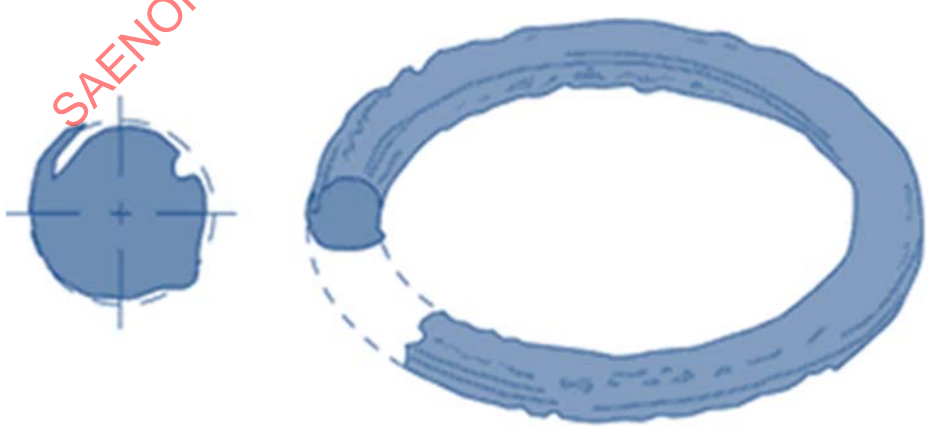

FIGURE 1 - EXTRUSION AND NIBBLING

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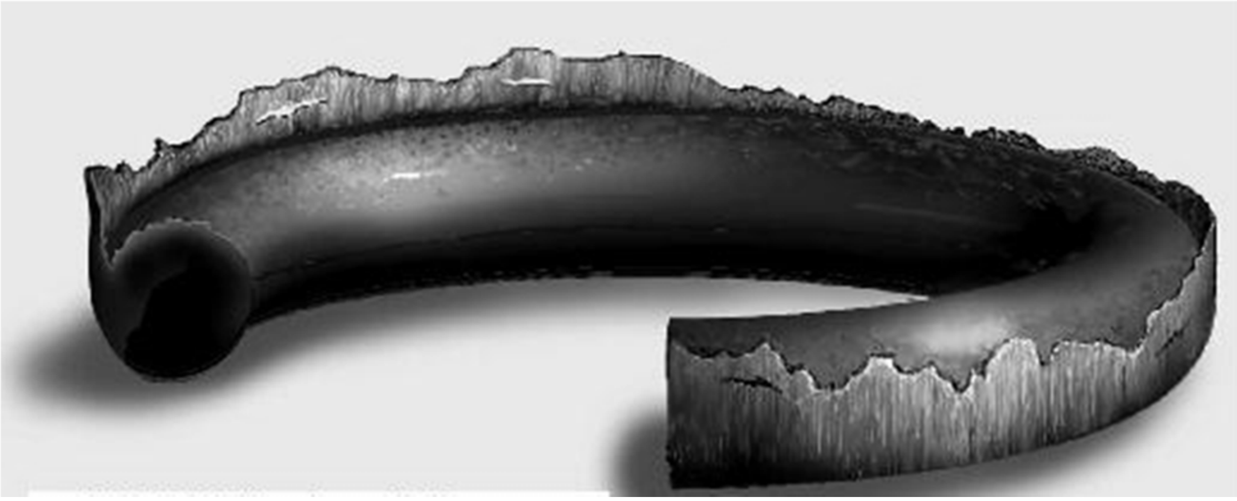

FIGURE 2 - EXTRUSION AND NIBBLING (USED WITH PERMISSION FROM R.L. HUDSON)

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FIGURE 3 - NIBBLING AND SKIVING

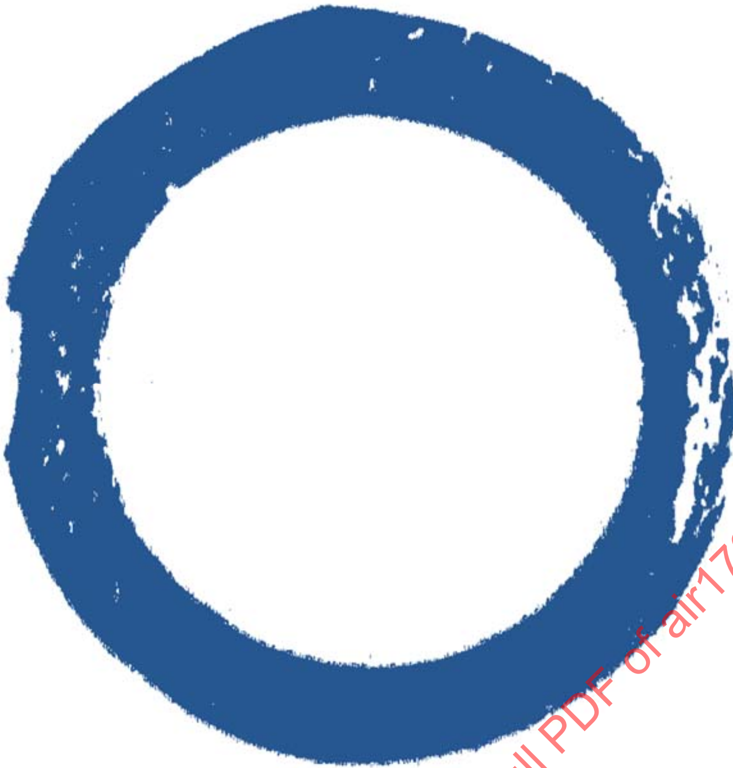

FIGURE 4 - NIBBLING AND ABRADING

FIGURE 5 - NIBBLING AND EXTRUSION

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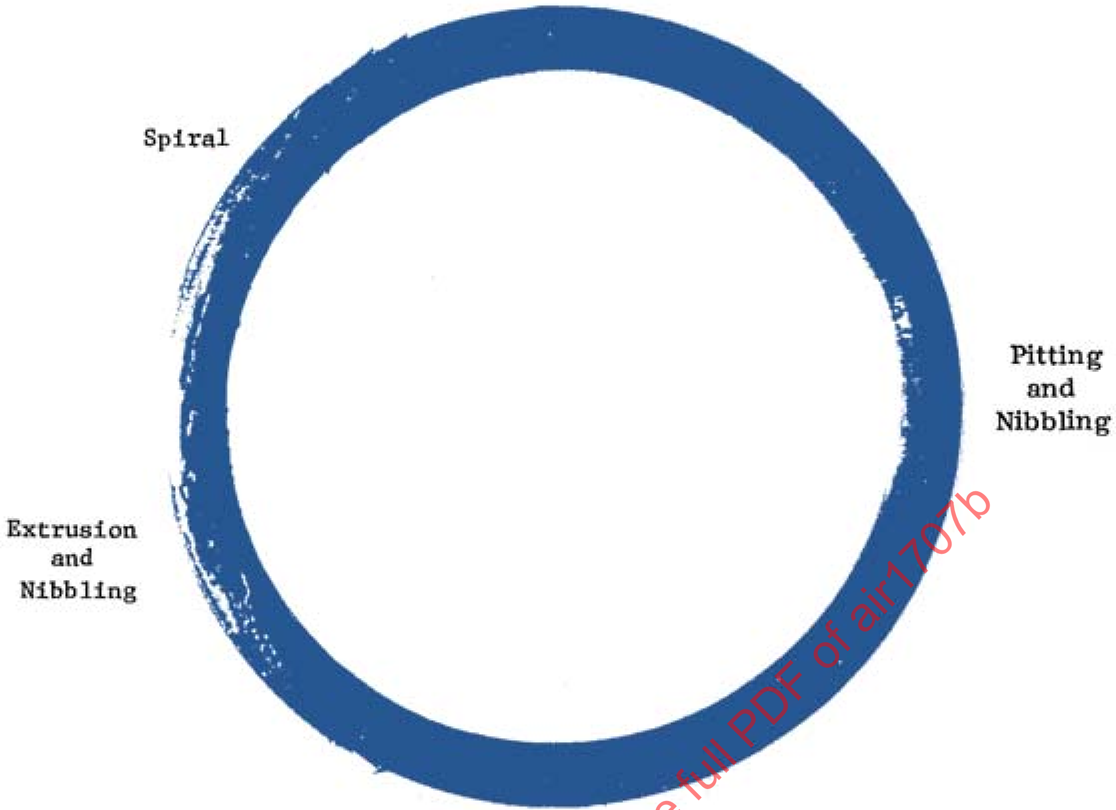

FIGURE 6 - NIBBLING, EXTRUSION, PITTING, AND SPIRAL FAILURE

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3.3 Spiral Failure

3.3.1 Occurrence

Usually associated with long stroke piston seals but can occur with dynamic rod seals. Has been observed even on short stroke pneumatic piston seals.

3.3.2 Appearance

Exhibits a deep spiral cut (usually at about 45 degree) into the O-ring cross-section.

3.3.3 Cause

Conditions which cause segments of the O-ring to slide and others to roll, simultaneously. The O-ring generally gets pinched or "hung up" at one point of its periphery. Side loads causing the O-ring to get caught in an eccentric component, uneven surface finishes, poor or uneven dispersion of lubricant and stroke speeds contribute.

3.3.4 Corrective Action

Improve metal surface finish to the 10 to 20 microinches (0.25 to 0.50 µm) range, improve lubrication, use backups or other antiextrusion devices if possible, reduce gap, and consider seals other than O-rings such as T-seals.

3.3.5 Examples

FIGURE 7 - SPIRAL FAILURE

FIGURE 8 - SPIRAL FAILURE (USED WITH PERMISSION FROM R.L. HUDSON)

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FIGURE 9 - SPIRAL FAILURE (PHOTO COURTESY OF PARKER HANNIFIN)

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3.4 Abrasion

3.4.1 Occurrence

Dynamic seals, either reciprocating or rotary.

3.4.2 Appearance

Flat area on one side of cross-section of O-ring where moving contact is made with metal component. Frequently shows wear lines on the cross-section parallel to motion of the seal.

3.4.3 Cause

Too rough or too smooth metal surfaces, poor lubrication, high temperatures, or fluid contamination.

3.4.4 Corrective Action

Use recommended metal finishes, provide adequate lubrication, use O-ring material compatible with service temperature, and eliminate fluid contamination. Rapid wear can be expected with finishes below 5 microinches (0.13 µm).

3.4.5 Examples

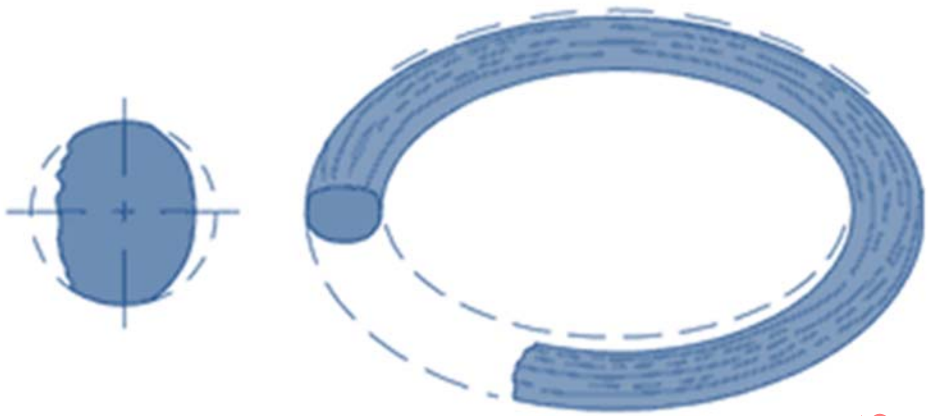

FIGURE 10 - ABRASION

FIGURE 11 - ABRASION ON ONE SIDE

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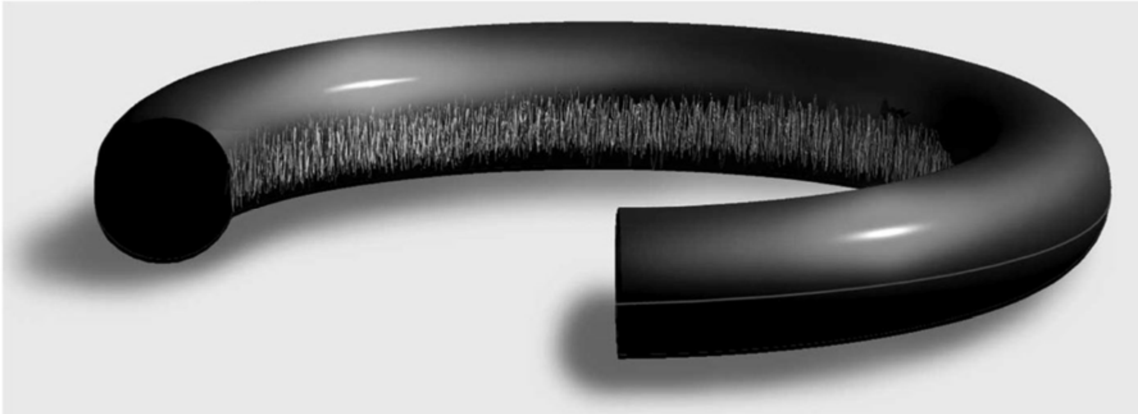

FIGURE 12 - ABRASION (USED WITH PERMISSION FROM R.L. HUDSON)

3.5 Compression Set

3.5.1 Occurrence

Dynamic and static seals.

3.5.2 Appearance

Flat area on both sides of O-ring cross-section in the area being squeezed.

3.5.3 Cause

Temperature too high (either environmental or frictional) causing hardening, excessive volume increase from fluid causing overfill, excessive squeeze to achieve seal, O-rings not completely vulcanized, or use of compound with poor set properties. In extremely rare cases, this can also be caused if a ring is over-cured (reversion.)

3.5.4 Corrective Action

Use O-ring material compatible with fluid and temperature service, minimize conditions which increase service temperature, review squeeze to be sure it is proper, and use an improved, low-set compound if available. A good quality, well-inspected O-ring is important.

3.5.5 Examples

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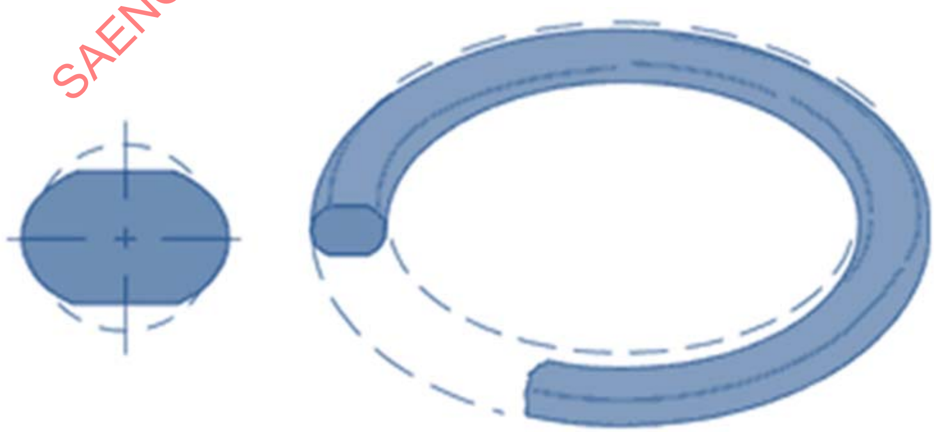

FIGURE 13 - COMPRESSION SET

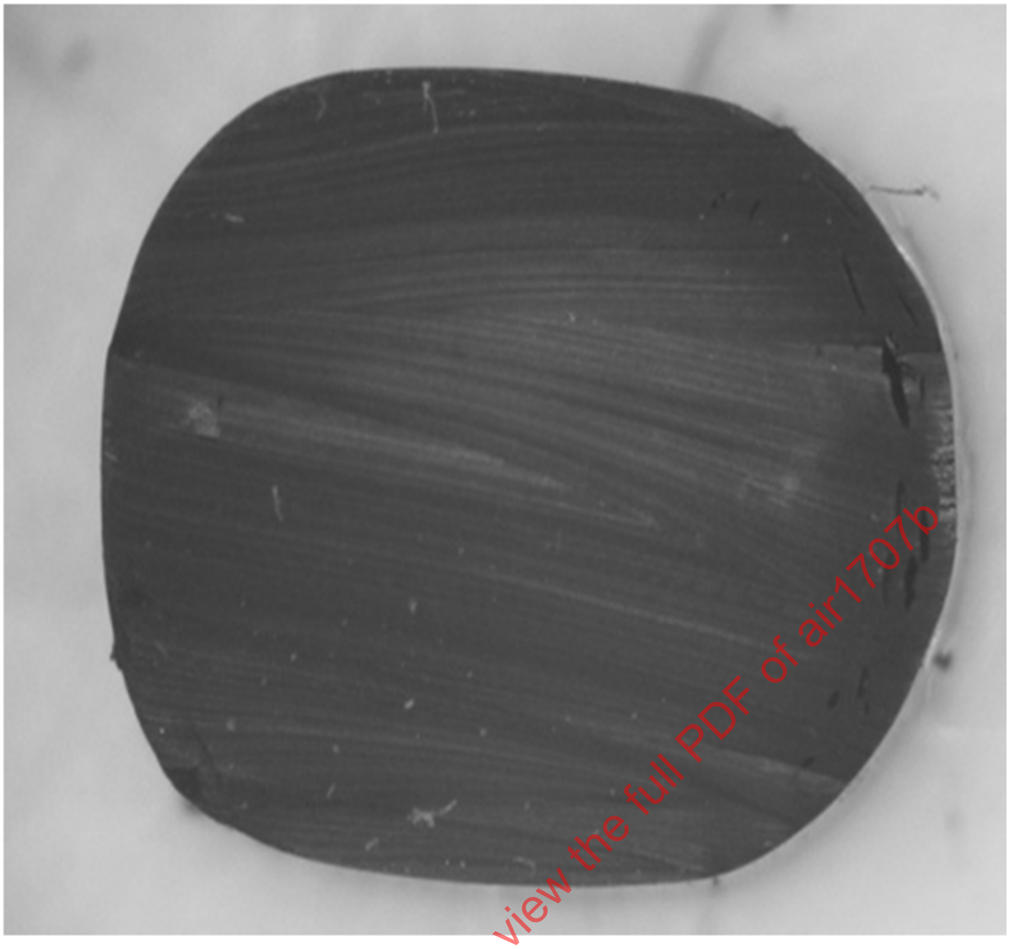

FIGURE 14 - COMPRESSION SET ON THREE SIDES (CROSS-SECTION)

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3.6 Weather or Ozone Cracking

3.6.1 Occurrence

Dynamic or static seals under stress and exposed to atmosphere containing ozone and air pollutants.

3.6.2 Appearance

Many small cracks perpendicular to the direction of stress may be small enough to be unseen with unaided eye or large enough to progress entirely through the cross-section (also see 4.8.3). Crazing of the outside surface of the O-ring is the most common.

3.6.3 Cause

Ozone attacks unsaturated or double bond points in polymer chain of some polymers causing chain scission. The damage is usually seen on the outside surface, exposed to the atmosphere.

3.6.4 Corrective Action

If conditions of service cannot be remedied, the rubber material must be changed. Use rubber materials that are saturated and inherently resistant to ozone attack. Change storage conditions to reduce exposure time to detrimental environment. Sufficient improvement can, at times, be obtained by using rubber compounds with antiozonant additives.

3.6.5 Examples

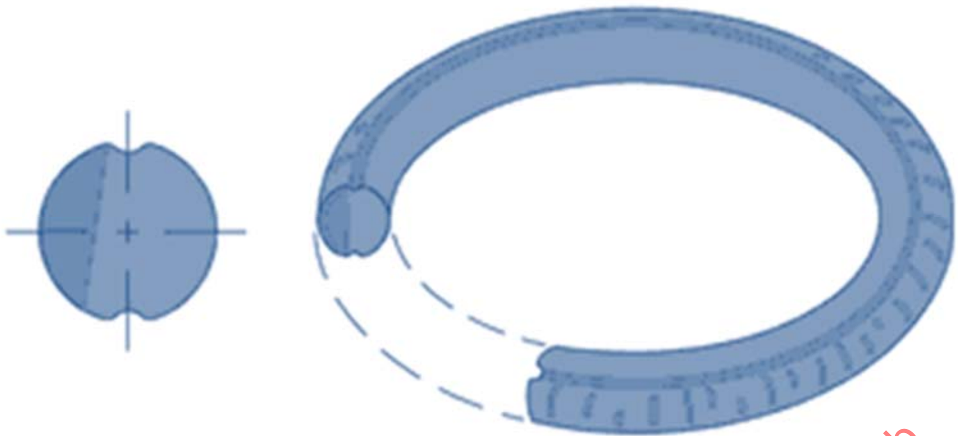

FIGURE 15 - WEATHER OR OZONE CRACKING

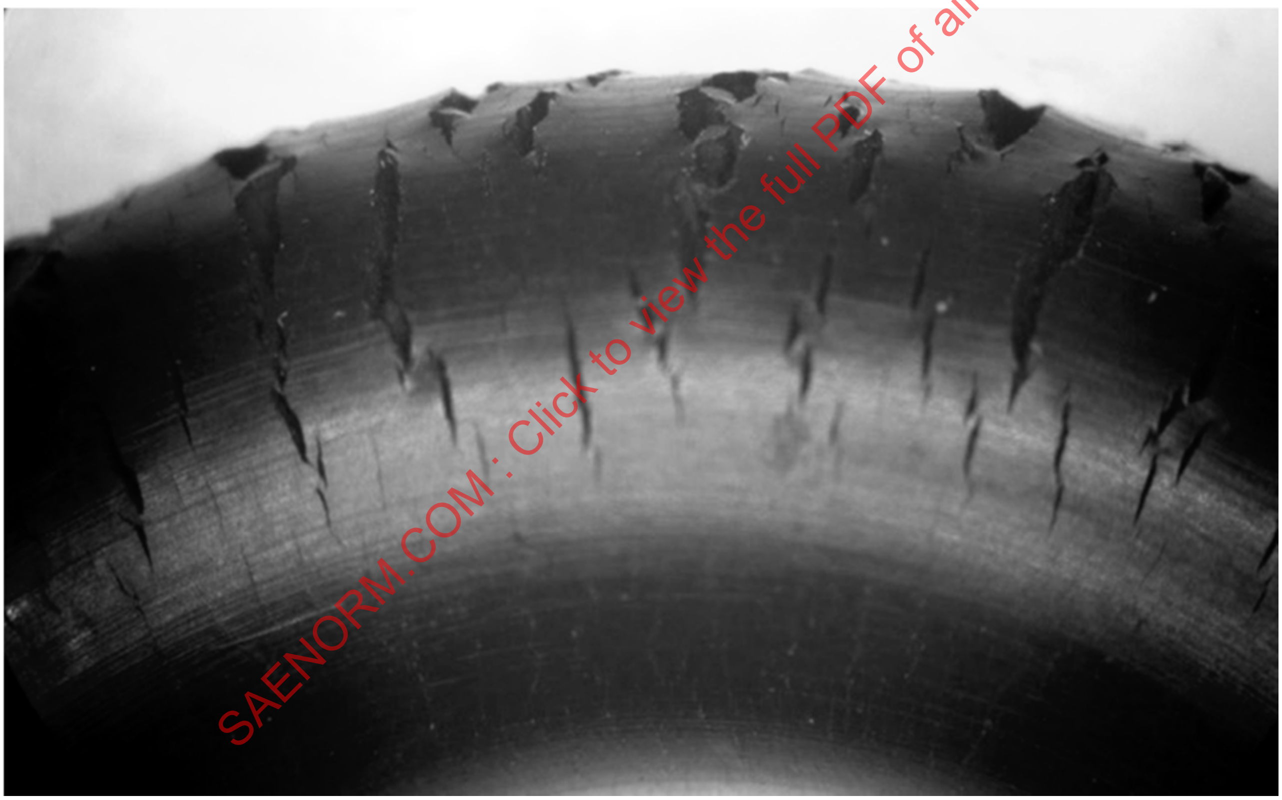

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FIGURE 16 - CRACKING FROM OZONE

FIGURE 17 - CRACKING FROM OZONE

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3.7 Heat Hardening and Oxidation

3.7.1 Occurrence

Dynamic or static seals subjected to elevated temperatures and atmosphere. Common in pneumatic or air service.

3.7.2 Appearance

Hardening of the rubber begins at the surface and progresses through the entire O-ring cross-section. Hardening is accompanied by high compression set if O-ring is under compression.

3.7.3 Cause

Environmental temperature and oxygen exposure are too high for the selected rubber material, causing hardening due to additional cross-linking in the rubber, evaporation of rubber plasticizer, or oxidation. It may be a combination of these.

3.7.4 Corrective Action

Decrease service temperature, select a rubber material with better resistance to high-temperature and/or oxygen exposure, or protect surface from oxygen exposure (as wiper seals).

3.7.5 Examples

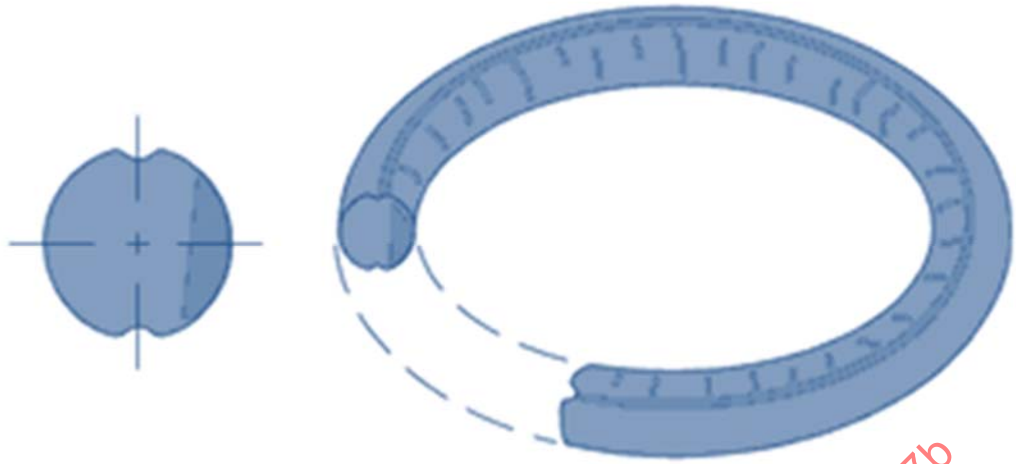

FIGURE 18 - HARDENING AND OXIDATION

FIGURE 19 - WEATHER CRACKING (USED WITH PERMISSION FROM R.L. HUDSON)

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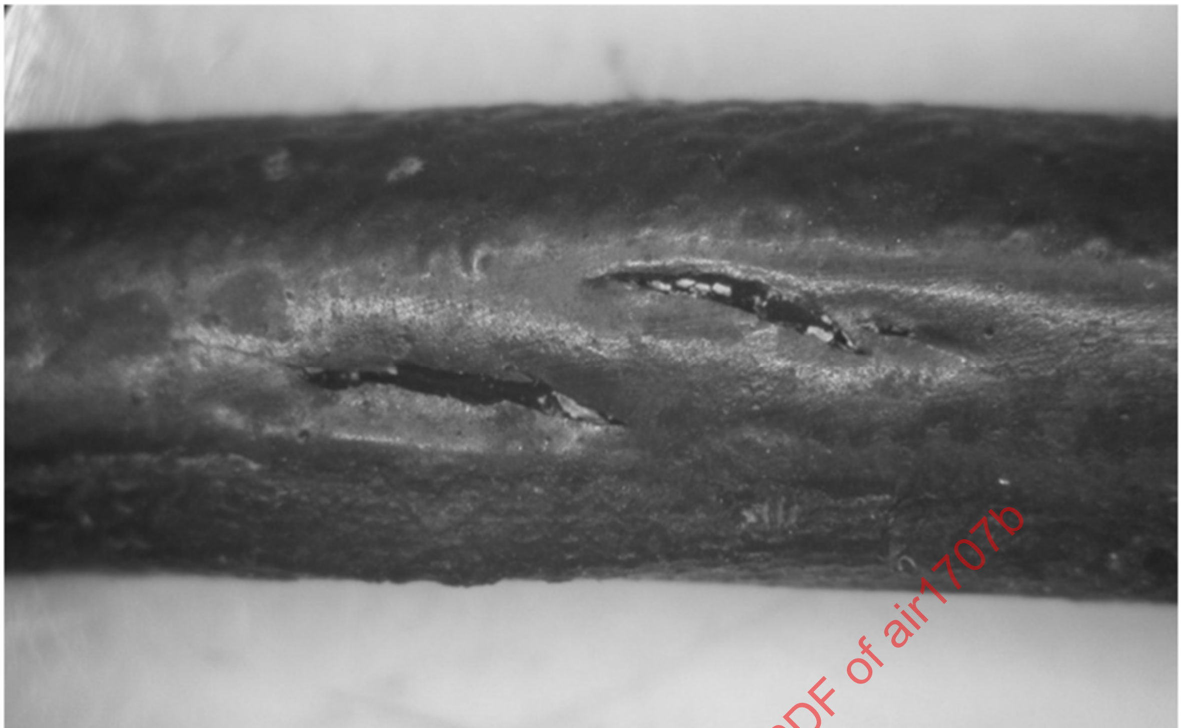

FIGURE 20 - HARDENING AND PITTING

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3.8 Plasticizer Extraction

3.8.1 Occurrence

Dynamic and static seals usually in fuel systems subject to dry-out periods, but occasionally in other systems.

3.8.2 Appearance

Small cracks in stressed area of O-ring cross-section, accompanied by loss in volume. This is often difficult to detect with a visual inspection.

3.8.3 Cause

Extraction of plasticizer by service fluid followed by evaporation of service fluid during dry-out period. Results are hardening of the rubber material and decrease in elongation to the extent that cracks appear where stressed. This condition is accelerated in the presence of ozone.

3.8.4 Corrective Action

Assuming service conditions cannot be improved, change to a compatible rubber material with low or no extractable plasticizer content.

3.8.5 Examples

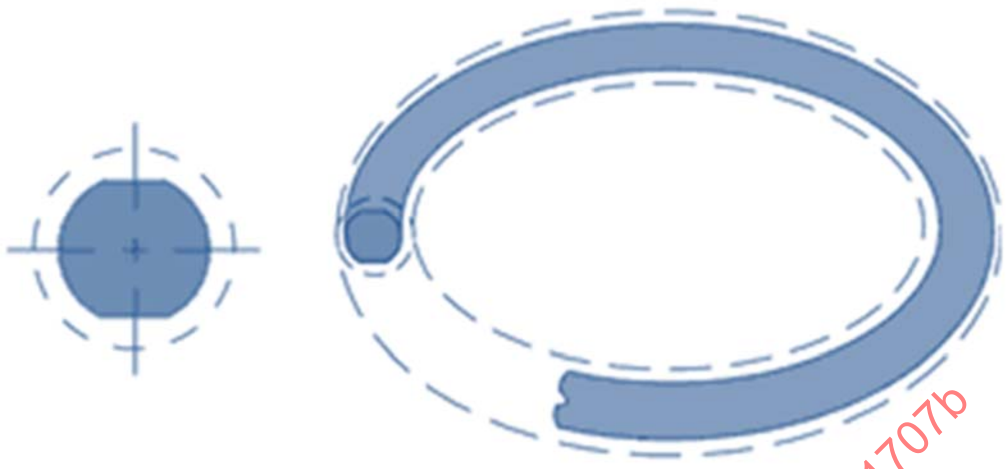

FIGURE 21 - PLASTICIZER EXTRACTION

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3.9 Installation Damage

3.9.1 Occurrence

Dynamic and static seals usually installed with squeeze between inside and outside diameter of the O-ring, or stretching an O-ring over tube ends or threads.

3.9.2 Appearance

Short cuts or notches or a "shinned" surface or a "skived" cut that can extend at a uniform thickness clear around the periphery of the O-ring and can continue through the cross-section as if it were being peeled. May also present as spiraling or twisting in certain applications.

3.9.3 Cause

Sharp corners on mating metal parts, threads, or insufficient lead-in chamfer; inside diameter of O-ring too small on rod seal or too large on piston seal installation. Blind grooves in multiple port valves are especially troublesome.

3.9.4 Corrective Action

Adjust dimensions of metal components and O-rings to eliminate cutting or pinching of seals when possible. Lead-in chamfers should be 20 degrees maximum and "break" sharp corners of chamfer and groove edges. Use tubular installation tools to cover threads and sharp corners during O-ring installation. If feasible in the application, use an elastomer that is more resistant to mechanical damage (e.g., EPDM instead of silicone).

3.9.5 Examples

FIGURE 22 - INSTALLATION DAMAGE (USED WITH PERMISSION FROM R.L. HUDSON)

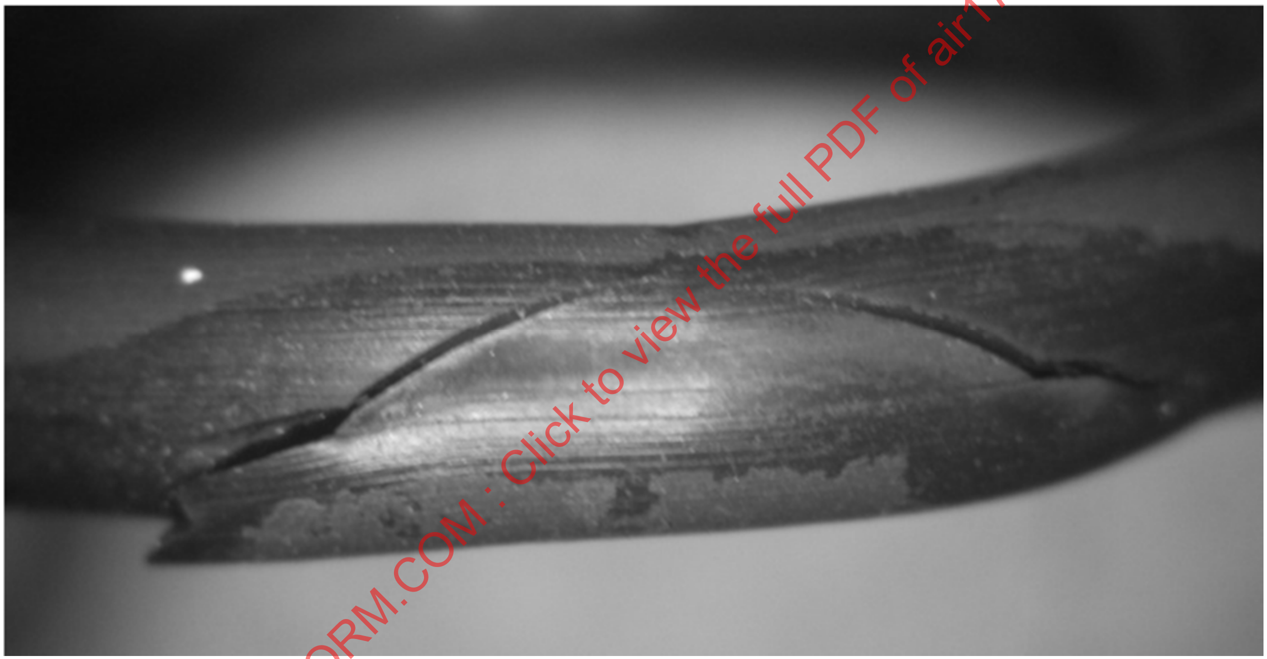

FIGURE 23 - TWISTED AND PUNCTURED INSTALLATION DAMAGE

FIGURE 24 - SKIVED INSTALLATION DAMAGE

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