

AEROSPACE INFORMATION REPORT

SAE AIR1707

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A

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Patterns of O-ring Failures

FOREWORD

Changes in this Revision are format/editorial only.

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.

2. 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.

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, 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 - 0.002 in. (0.025 - 0.050 mm). T-seals that fit into the same gland may also be substituted.
- 3.2.5 Examples.

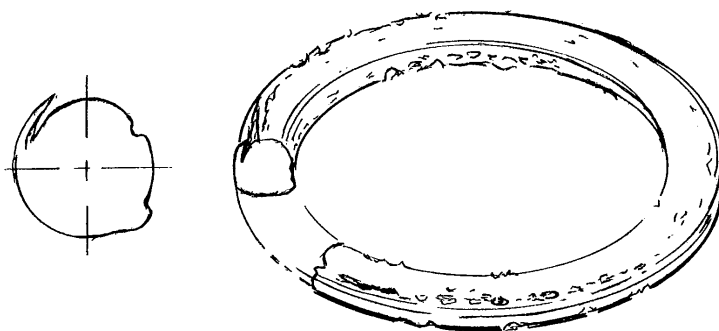


FIGURE 1 - Extrusion and Nibbling

Extrusion and
Nibbling



FIGURE 2 - Extrusion and Nibbling



FIGURE 3 - Nibbling and Skiving

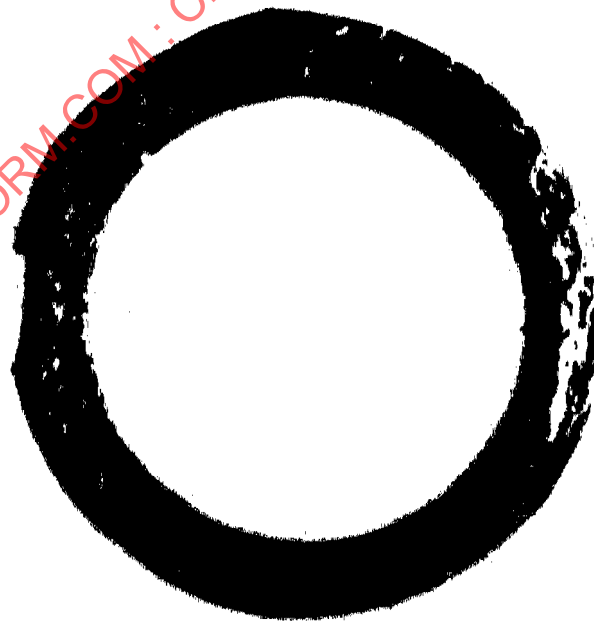


FIGURE 4 - Nibbling and Abrading

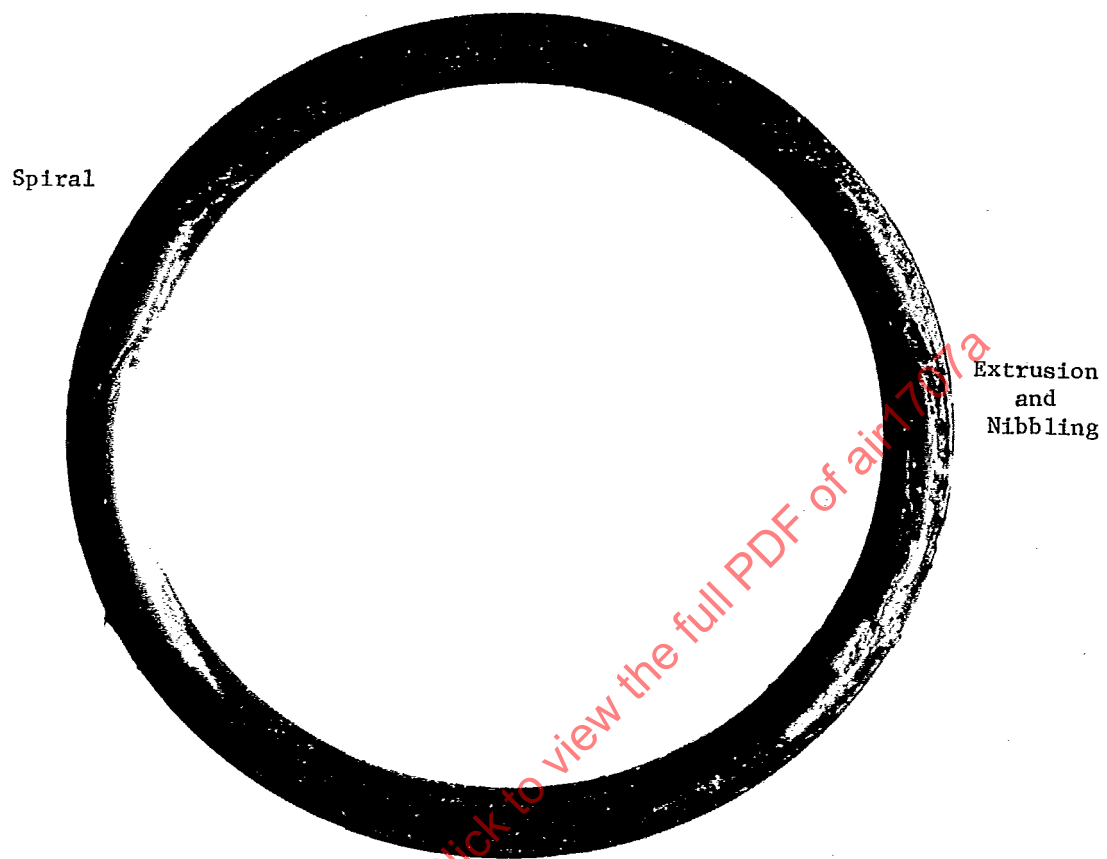


FIGURE 5 - Nibbling and Extrusion

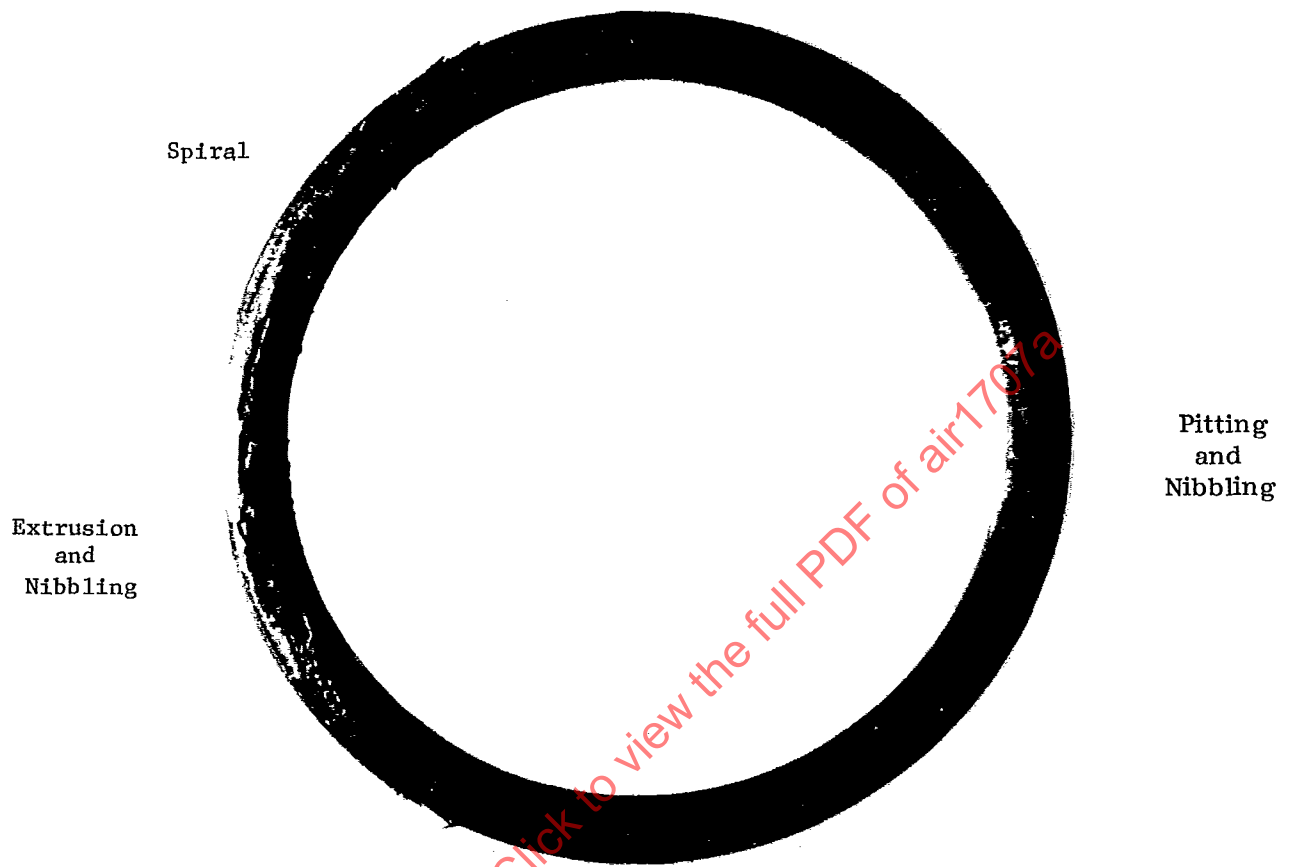


FIGURE 6 - Nibbling, Extrusion, Pitting, and Spiral Failure

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°) 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 - 20 $\mu\text{in.}$ (0.25 - 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:

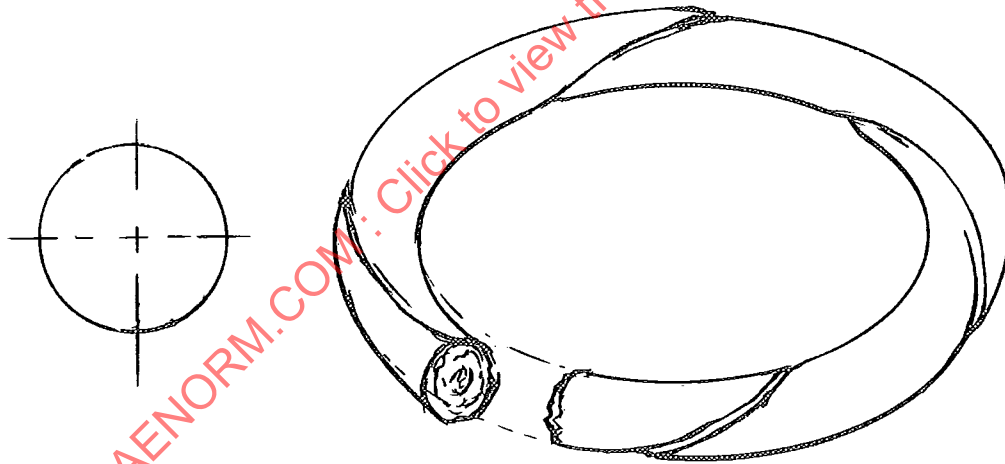


FIGURE 7 - Spiral Failure



FIGURE 8 - Spiral Failure

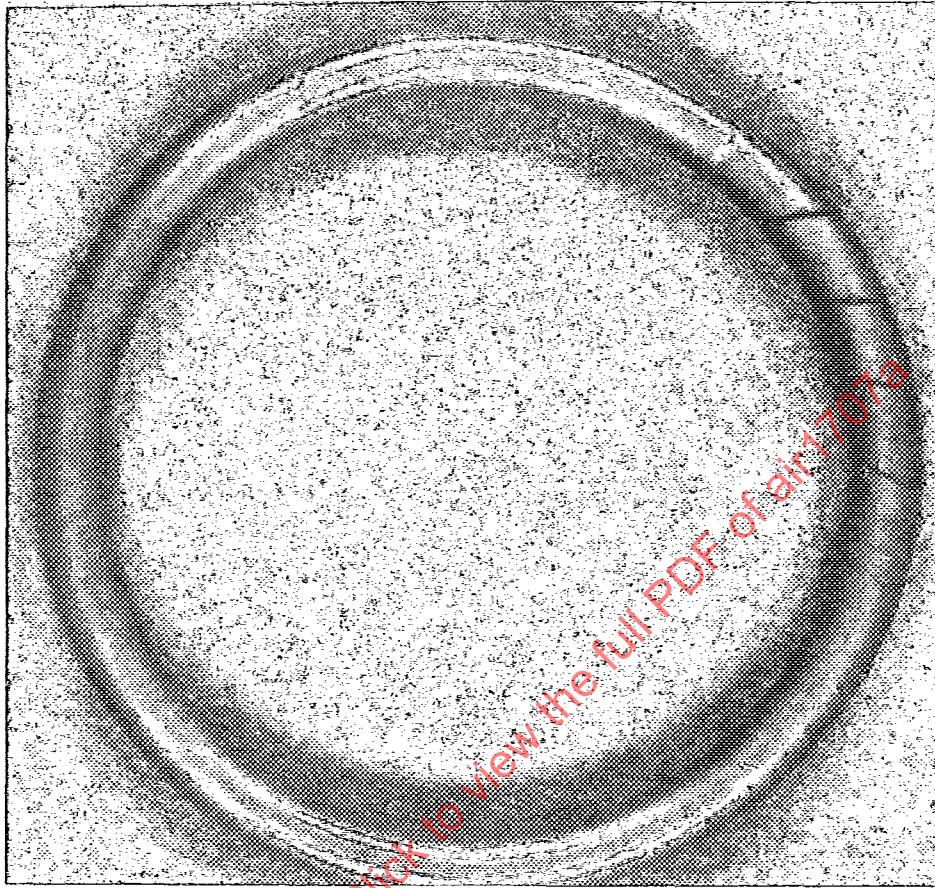


FIGURE 9 - Spiral Failure

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 $\mu\text{in.}$ ($0.13 \mu\text{m}$).

3.4.5 Examples:

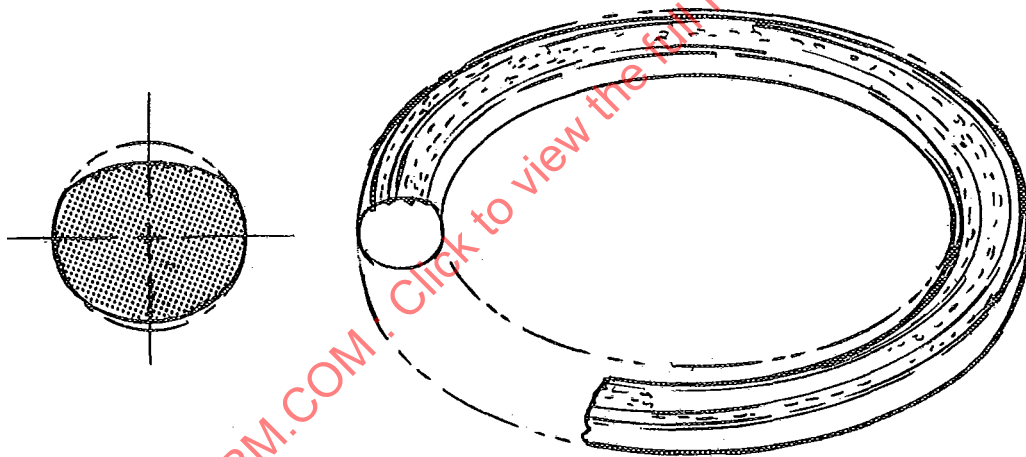
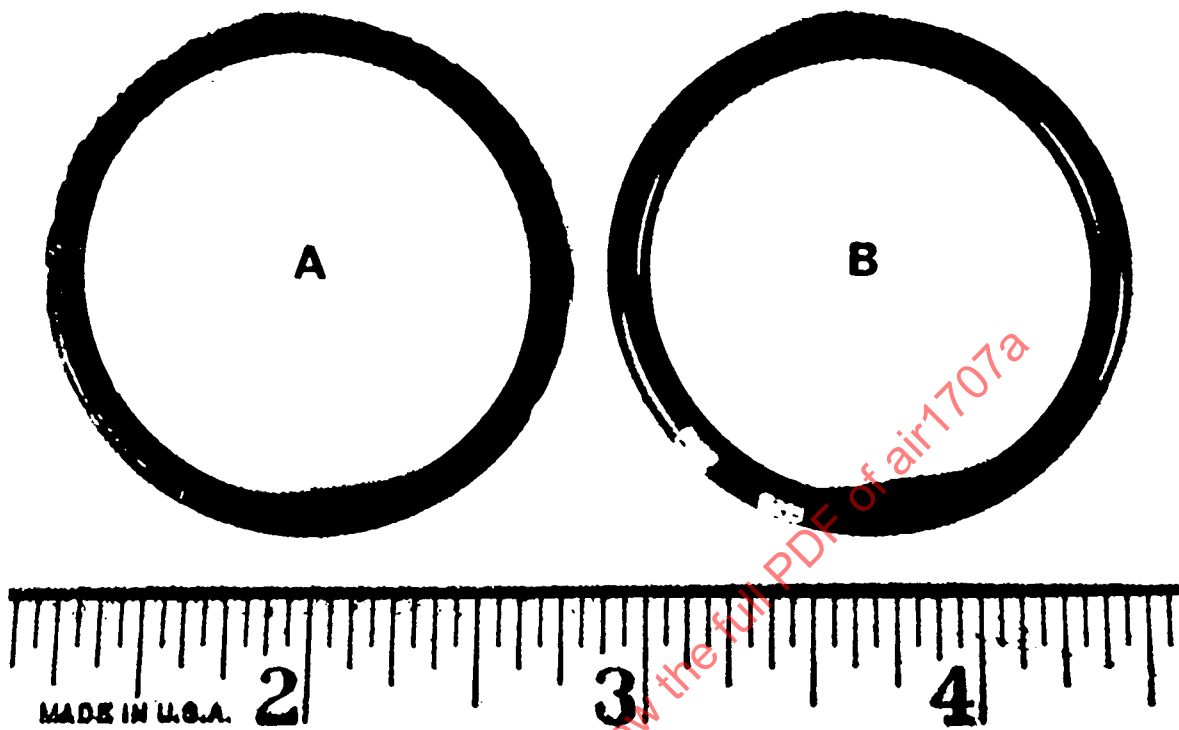


FIGURE 10 - Abrasion



A = Severely abraded and nibbled
B = Normal condition after same period of service
Scale as shown

FIGURE 11 - Abrasion

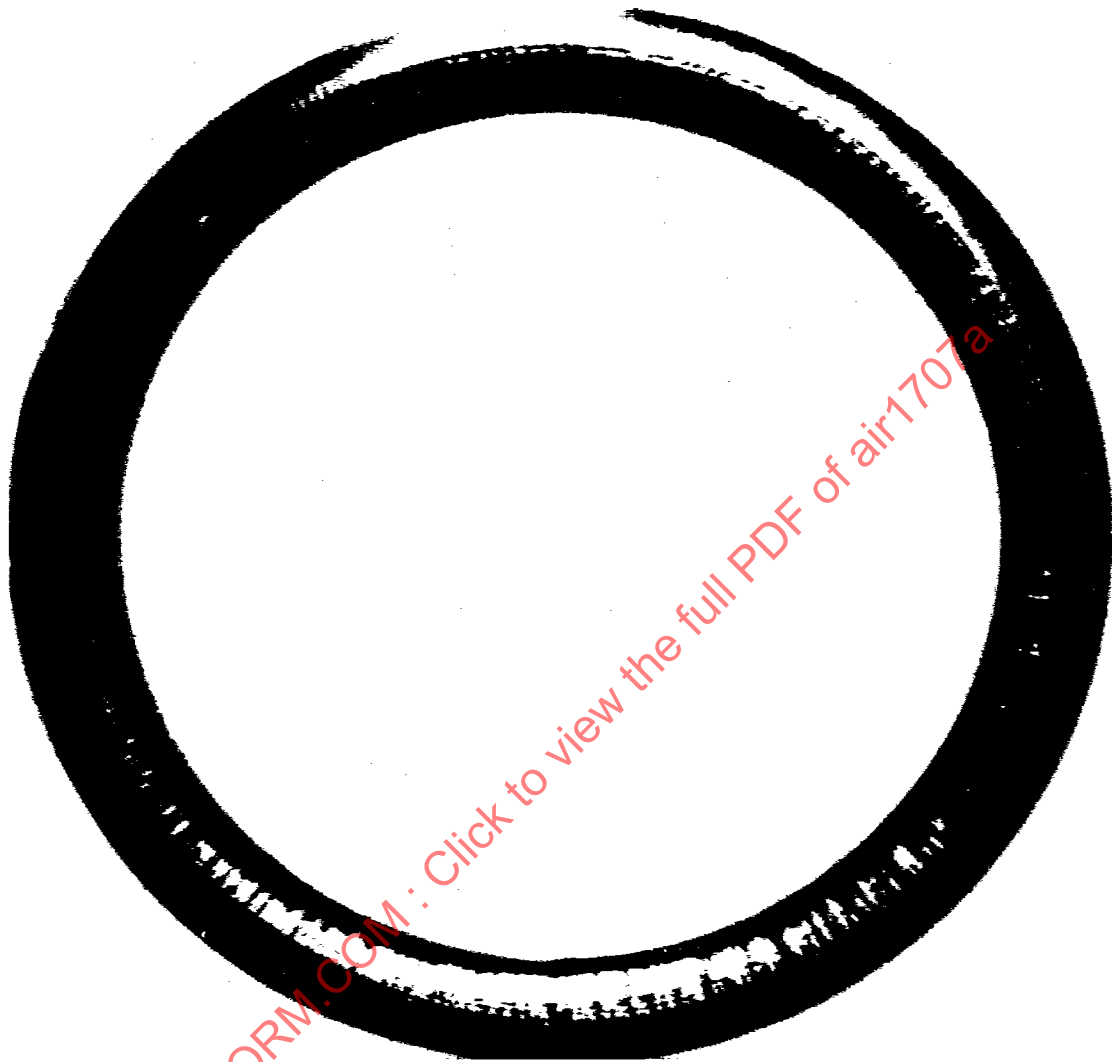


FIGURE 12 - Abrasion



FIGURE 13 - Abrasion at Color Code

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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.

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:

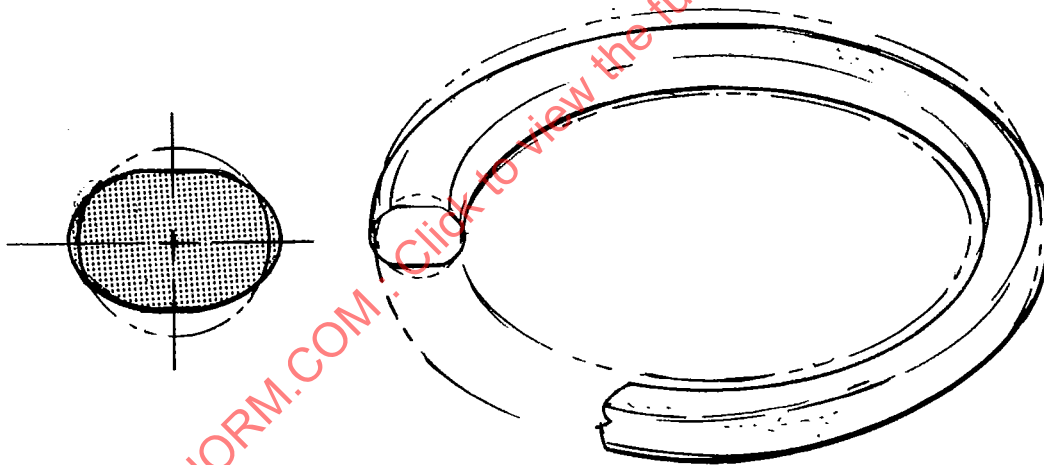


FIGURE 14 - Compression Set

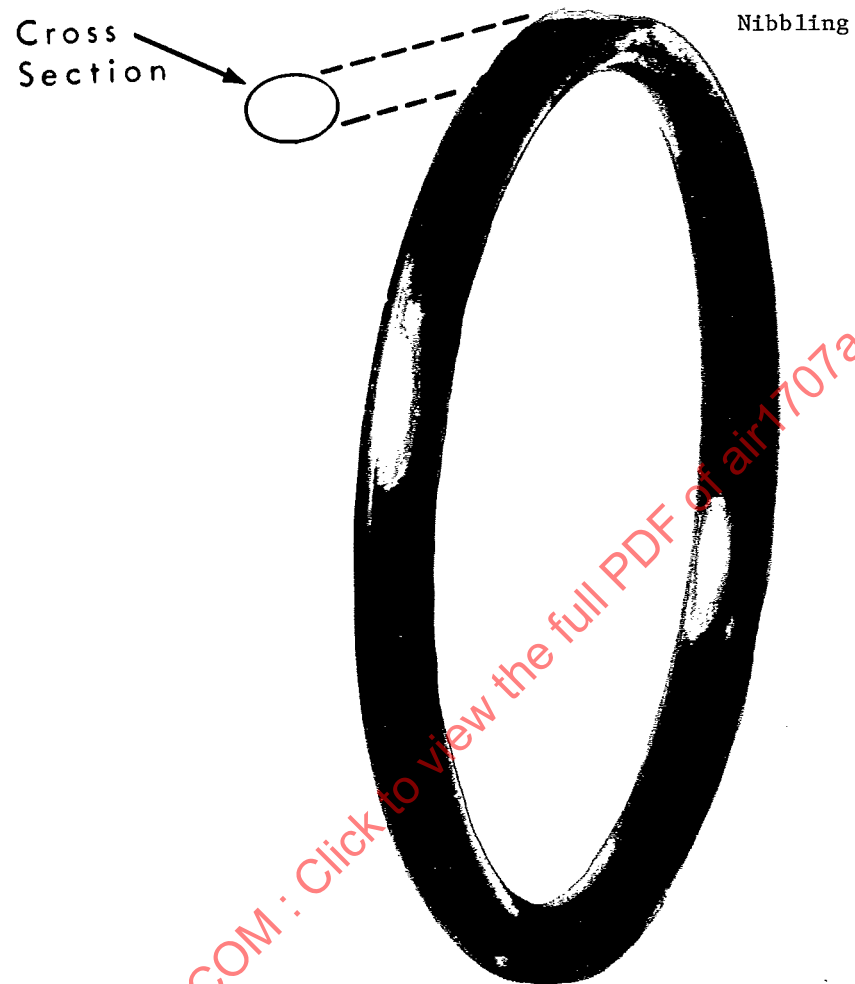


FIGURE 15 - Compression Set

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 3.8.3). Cracking 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. Usually, the outside surface, that area exposed to the atmosphere, is where the damage is seen.
- 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:

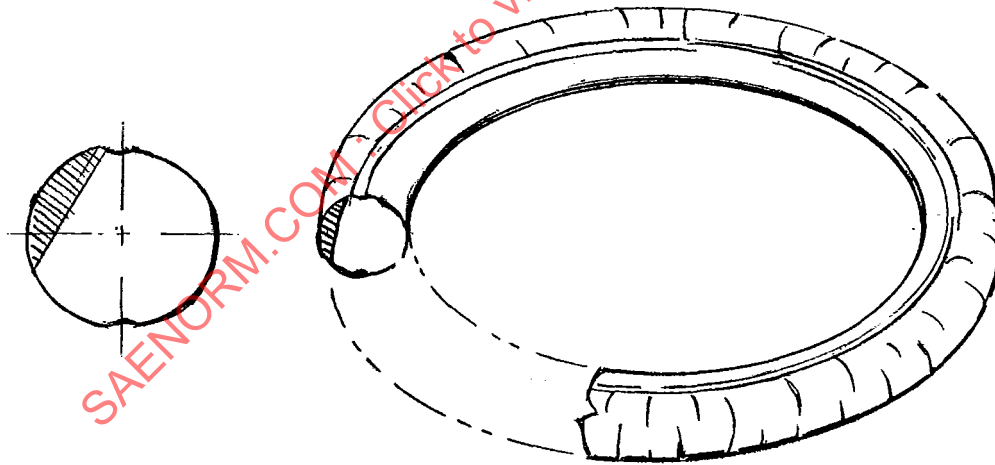


FIGURE 16 - Weather or Ozone Cracking

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, which begins at the surface and progresses through the entire O-ring cross-section. Accompanied by high compression set if O-ring is under compression.
- 3.7.3 Cause: Environmental temperature is too high for 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, use oxidation resistant material with better high-temperature characteristics, or protect surface from oxygen exposure (as wiper seals).
- 3.7.5 Examples:

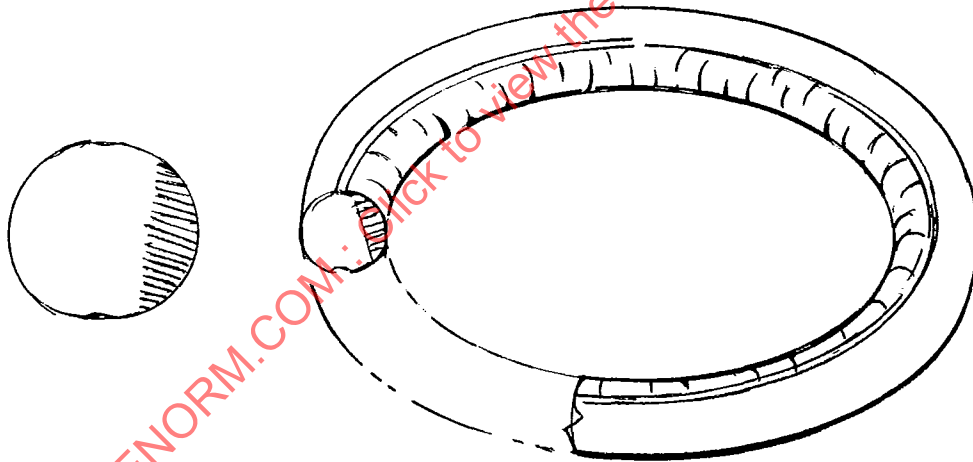


FIGURE 17 - Hardening and Oxidation



20X

FIGURE 18 - Weather Cracking



FIGURE 19 - Hardening and Pitting

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.
- 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:

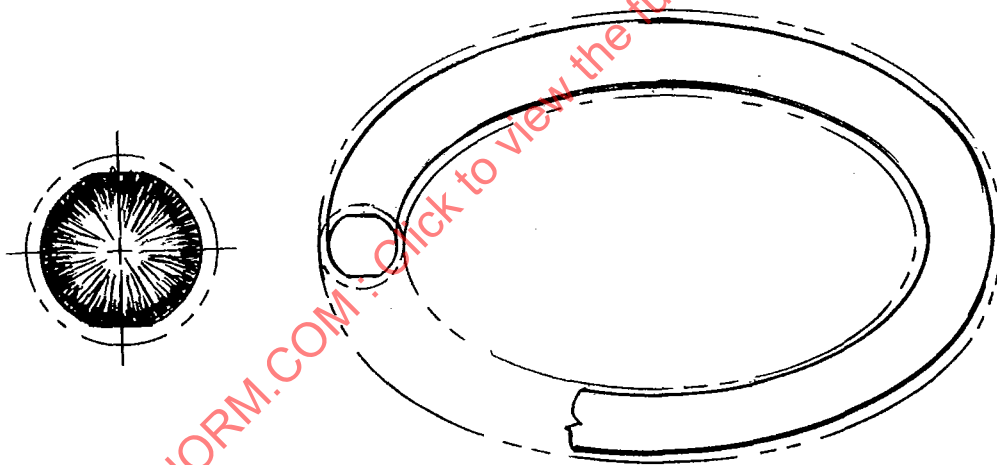


FIGURE 20 - Plasticizer Extraction