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Nitrile O-ring Cracking: A Case of Vacuum Flange O-ring Failures

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Abstract **- Recent nitrile O-ring cracking failures in ISO-KF (International Organization for Standardization Klein Flange) vacuum flange connections in glovebox applications was observed. An investigation of a single "isolated" O-ring failure leads to the discovery of cracked nitrile O-rings on multiple gloveboxes and general purpose piping, roughly 90% of the nitrile O-rings removed for inspection show evidence of visible cracking. The identified O-ring cracking is similar to ozone degradation. Material and ambient air testing indicate no abnormal materials or elevated ozone levels. The contributing factors of O-ring failure evaluated and determined to be nitrile material sensitivity to long term air exposure, inadequate storage practices, and poor installation techniques. A discussion of O-ring material properties and considerations for O-ring material selection are presented in the context of lessons learned from the nitrile O-ring cracking investigation.**

Introduction

ISO-KF vacuum flange connections can be found in glovebox applications on vacuum pumps, recirculation lines, and other low pressure connections. The integrity of the connection relies on an O-ring clamped between two flange faces. Recently the Idaho National Laboratory experienced difficulty maintaining a high purity inert environment on a relatively new glovebox during normal operations. Helium leak testing identified one leaking ISO-KF25 flange on the recirculation piping near the glovebox purification unit. Although initially considered an isolated event, all of the ISO-KF connection O-rings near the glovebox purification unit were replaced. It was surprising to find that all of the O-rings replaced exhibited visible surface cracking. Concerned by this finding, a wholesale replacement of ISO-KF connection O-rings was conducted on the remainder of the glovebox and several additional gloveboxes in the area. The majority of the replaced O-rings were nitrile material, a few were Viton® material. Roughly 90% of the ISO-KF connection nitrile O-rings demonstrated visible surface cracking, cracking was not found on any Viton® O-rings.

O-ring Damage

Figure 1: Minor Cracking

The cracked O-rings ranged in service age from 8 months to 4 years. The cracking appears on the outside diameter of the O-ring and is absent on the inside O-ring diameter. The material shelf life provided by the O-ring manufacturer was 5 years. Although the manufacturer provided little information on the service life, it was anticipated that the O-rings would provide at least 5 years of service in this low pressure inert gas environment.

A broad range of surface cracking severity was noted, the most significant cracking extended through about half of the material thickness, see Figure 1 and Figure 2. Two general observations can be made related to the severity of the surface cracking. First, O-rings installed for longer periods of time exhibited more significant cracking. Second, well lubricated O-rings exhibited less cracking compared to O-rings of the same age which were installed dry. The dry O-rings are an apparent oversight by the installer as all of the O-rings should have been lightly lubricated at the time of installation. The O-ring surface cracking is visually comparable to ozone or weather deterioration in nitrile material.

Figure 2: Significant Cracking

The location of the cracking, on the outside diameter, is consistent with the O-ring surface exposed to room air, whereas the inside diameter is exposed to the glovebox environment, typically inert argon gas.

Other installation issues and poor practices were noted, some ISO-KF connections exhibited damaged centering rings or compression marks on the nitrile O-ring material, see Figure 3. The damaged centering rings are a clear indication of flange misalignment and inattentive installation practices. The compression marks are another symptom of improper lubrication, the O-ring material appears to compress unevenly due to friction when the flanges are clamped together.

Figure 3: Centering Ring Damage

Material and Service Conditions

In order to rule out counterfeit material as the cause of failure, the O-ring material was confirmed by reviewing the purchasing records and by independent material analysis. Purchasing records indicated the material to be nitrile rubber. The O-ring material was also confirmed through FTIR (Fourier Transform Infrared Spectroscopy) analysis. Material hardness measurements indicated 70 to 80 Shore A hardness as desired. (1) This evidence supports the conclusion that the O-ring material is nitrile, as it was purported to be.

Considering the surface cracking was visually similar to weathering and ozone deterioration a

review of the service conditions was conducted and indicated no unusual challenges. The ISO-KF flange connections were all used indoors, at low pressures, and room temperatures. No source of UV light or significant ionizing radiation were present. No sources of excess oxygen or ozone were identified and subsequent air monitoring confirmed typical atmospheric oxygen levels and ozone levels less than the instrumentation detectable limit of 25 ppb. Lacking evidence of counterfeit material, ozone, or aggressive service conditions, more generic material incompatibilities were explored.

Contributing Factors

O-ring samples were sent to two independent O-ring manufacturers for evaluation. (1) (2) The manufacturers generally agreed that the cracking was caused by loss of plasticizer by outgassing, a common issue with nitrile material, and likely not as a result of excessive ozone. Both manufacturers suggested avoiding the nitrile material for applications where the O-ring is continuously exposed to air. The evaluations from the O-ring manufacturers support a conclusion that the O-ring cracking is a result of material and application incompatibility rather than previously unidentified environmental conditions. Careful maintenance and regular O-ring replacement would be a necessary prerequisite for successful nitrile O-ring use in applications where extended exposure to air is anticipated.

A review of the storage and installation techniques showed additional opportunities for improvement. The O-ring in ISO-KF flange connections are mounted on a metal centering ring which aid in positioning the O-ring and align the two mating flanges. In most cases the O-rings were purchased preinstalled on the metal centering ring, and typically stored four to six months prior to installation. The stretched condition is undesirable, ideally the O-ring would be left in a natural condition until installation.

Figure 4: Unsealed Packaging

Another potential concern was identified in the O-ring packaging. The O-rings, preinstalled on a metal centering ring, were individually packaged but the packaging was not air tight as shown in Figure 4. This storage condition left the O-rings in a stretched condition, exposed to air, for extended periods of time and is considered a contributing factor to the observed rapid cracking in the nitrile material.

It was also observed that O-rings which were installed with lubrication generally exhibited less cracking over time compared to O-rings which were installed dry. The O-ring lubrication, or O-ring grease, acts as a protective layer against outgassing on the outer surface of the O-ring. Lubrication also aids in the installation process and prevents friction against the O-ring surface as the seal is compressed and clamped in place. The benefits of O-ring lubrication are well established by most O-ring manufacturers. (3)

It seems likely that the nitrile was selected by default rather than by conscious consideration. While the glovebox design documentation contained details of the window and transfer chamber seals, the ISO-KF flange connection O-ring material was absent from the documentation.

This oversight serves as a reminder to include all sealing materials, including ISO-KF flange O-rings and valve packing materials, in the design documentation.

Conclusions/Lessons Learned

The contributing factors of O-ring failure are determined to be nitrile material sensitivity to long term air exposure, inadequate storage practices, and poor installation techniques. Careful maintenance and regular O-ring replacement would be a necessary prerequisite for successful nitrile O-ring use in applications where extended exposure to air is anticipated. Proper storage practices would also be necessary in order to achieve the manufacture's suggested shelf life. Considering these meticulous prerequisites, the nitrile O-ring is poorly suited for many glovebox applications.

All sealing materials should be included in the glovebox design documentation. In this case the window and transfer chamber seals were closely specified, but the O-ring material was largely overlooked in the design documents. This material selection by default resulted in the installation of nitrile O-rings, which have proved to be poorly suited for the application.

Consideration should be given to O-ring materials better suited for continuous air exposure, such as Viton®, for general purpose glovebox applications. An O-ring material for all glovebox applications cannot be stated, and the final material decision should consider any application specific concerns.

References

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