Testing and Analysis

The Effects of Large Temperature Changes on Elastomer Seal Performance

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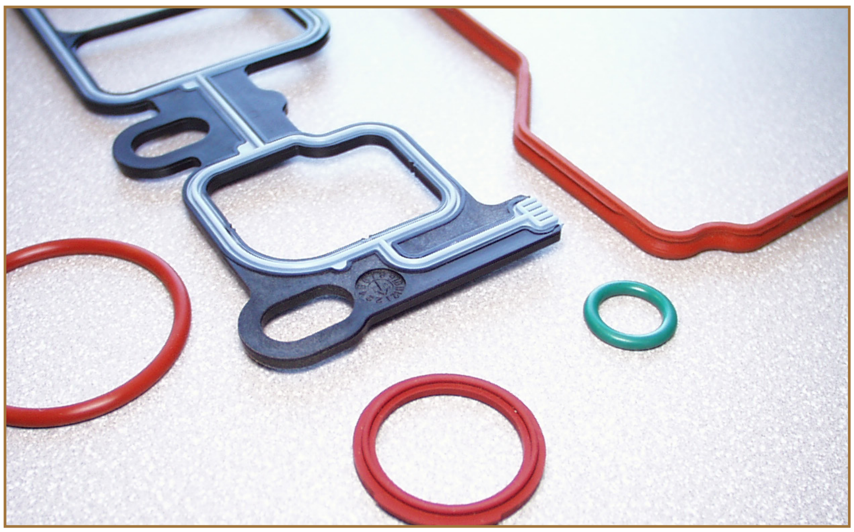

Figure 1, Typical Elastomer Seals including an O-ring, an Automotive Intake Manifold and a Compressor Seal

Introduction

Elastomer seals are often required to react against sealing surfaces with sufficient pressure to prevent a leak during large changes in temperature. Because the coefficient of thermal expansion of elastomers can be an order of magnitude greater than that of the surrounding sealing surfaces, the thermal expansion and thermal contraction of the elastomer seal associated with large temperature changes creates large stress changes within the elastomer seal.

In addition to the thermal expansion that occurs with increases in temperature, elastomeric seals also experience structural degradation or additional cross-linking at elevated temperatures. These effects can be very dramatic, especially the first time that the seal experiences the elevated temperature while constrained.

However, the changes in seal material properties that may eventually result in seal failure are often not evident until the elastomeric seal experiences lower temperature conditions. The structural degradation or change in material properties that were caused by the high temperature condition become apparent at low temperatures when during thermal contraction, the seal material may no longer remain sufficiently elastic to maintain a minimum sealing pressure.

To illustrate these effects, a typical sequence in the life of an elastomer seal will be examined in more detail.

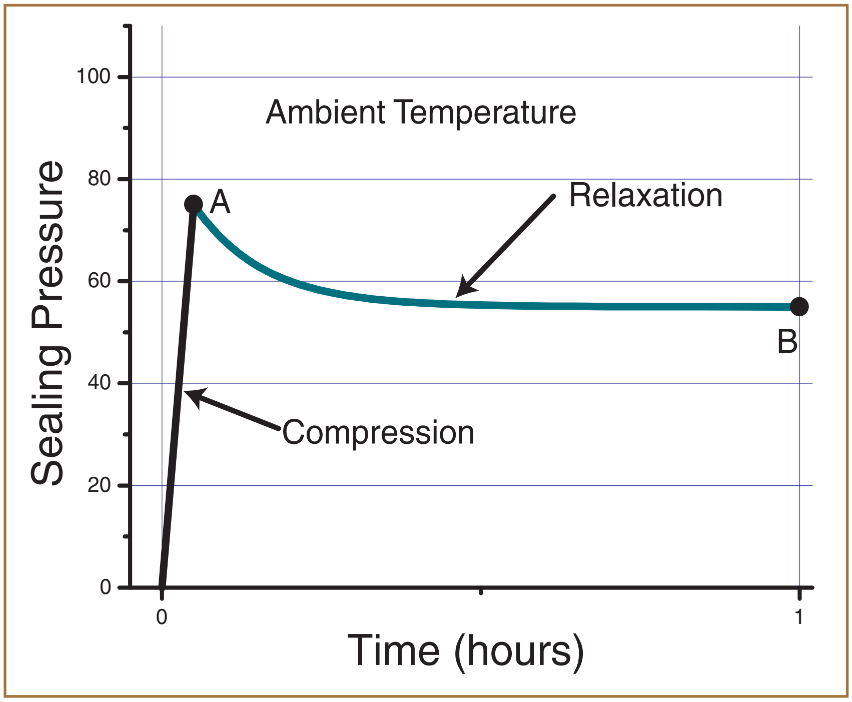

Figure 3, Initial Sealing Pressure Response to Seal Compression (Origin to A.) followed by Sealing Pressure Decay (A. to B.)

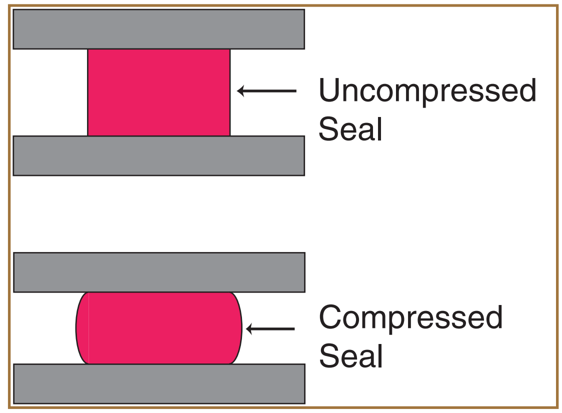

Figure 2, Compression of an Elastomer Seal

Initial Compression at Ambient Temperature

When an elastomer seal is initially compressed into position as shown in Figure 2, the sealing pressure increases as the seal is compressed. Once the seal is in position, the pressure decays. This pressure relaxation is very nearly a logarithmic decay such that the initial drop is quick but the pressure stabilizes during the first hour. This behavior is illustrated in Figure 3 where the reaction to compression is shown from the origin to point A followed by pressure decay from point A to point B.

First Time Increase in the Seal Temperature

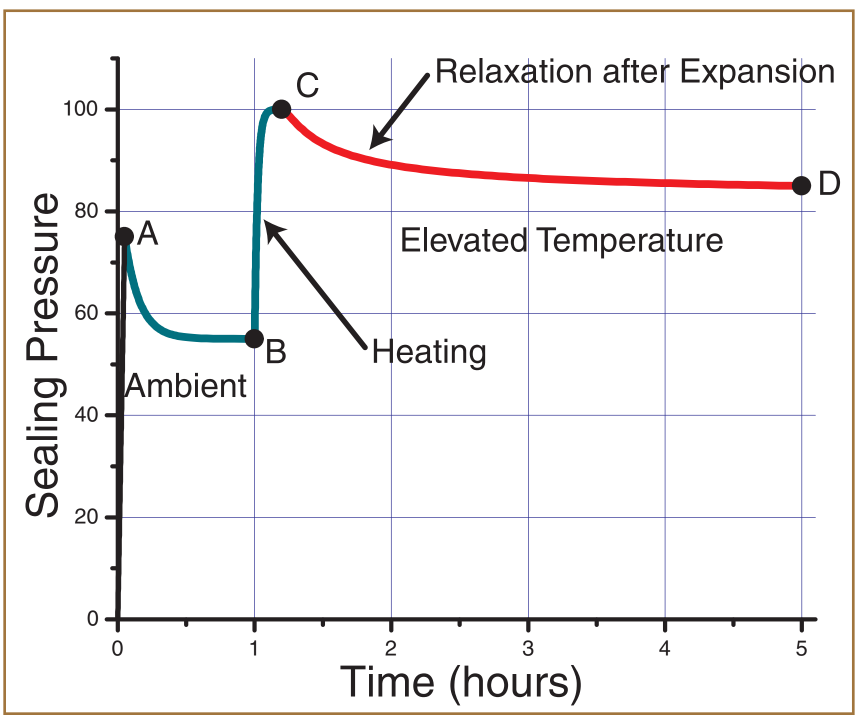

Figure 4, Sealing Pressure Increase (B. to C.) due to Thermal Expansion from Heating followed by Sealing Pressure Decay (C. to D.)

When the temperature of the elastomer seal is increased the seal expands. Generally, the sealing surfaces do not expand significantly so for purposes of this discussion, the seal compression is assumed to stay constant. Because the seal is constrained, the pressure in the seal increases with increasing thermal expansion as shown from point B to point C in Figure 4. When the thermal expansion is complete, the pressure will begin to decay as shown from point C to point D in Figure 4.

However, because of the combination of increased stress in the material and increased temperature, the structural properties of the material may also change. In some extreme cases the material will soften and the sealing pressure exerted by the seal will decrease to levels below the sealing pressure exerted at the earlier ambient condition. In Figure 4, this would result in point D falling to a lower pressure than point B. Or, the structural properties of the material may have no apparent degradation and the sealing pressure may only decay slightly during the high temperature condition. There may also be increased chemical activity that results in additional curing or cross-linking. Typically, the most dramatic effects occur within the first few hours at the elevated temperature.

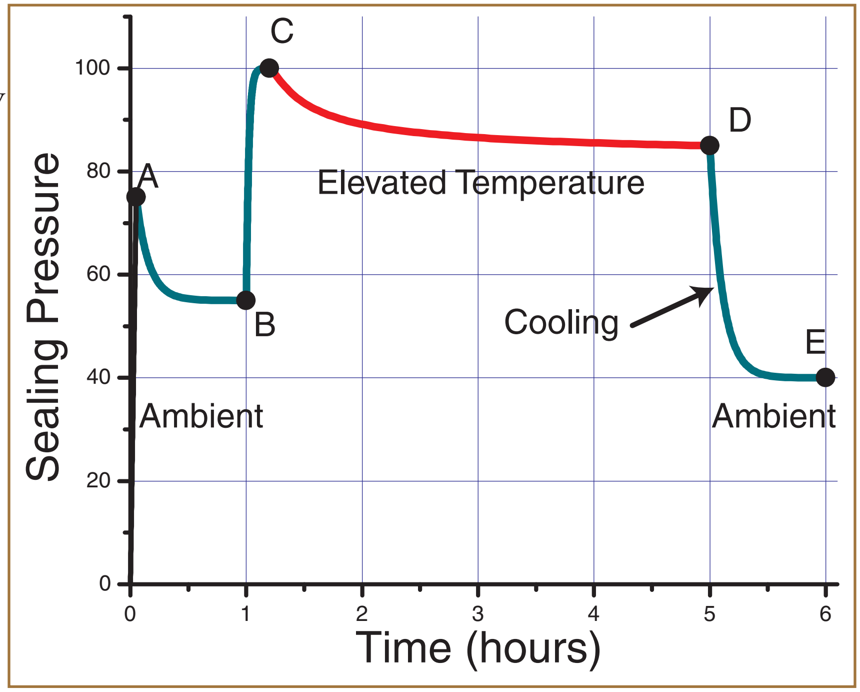

Figure 5, Sealing Pressure Decrease (D. to E.) due to Thermal Contraction from Cooling

Return to Ambient Temperature

If the temperature of the elastomer seal is then reduced to the previous ambient temperature, the seal will contract and there will be a reduction in sealing pressure as shown from point D to point E in Figure 5. It is informative to return to the previous ambient temperature because the sealing pressure can then be compared to the sealing pressure at ambient temperature prior to the elevated temperature condition. The sealing pressure at point E after the elevated temperature will be lower than point B prior to the elevated temperature. Sometimes the decrease is very dramatic. In any case, it is reasonable to associate this decrease in sealing pressure with the elevated temperature event.

Cooling to Sub-ambient Temperature

If we reduce the seal temperature, the seal will contract further and the sealing pressure will decrease as shown from point E to point F in Figure 6. The sealing pressure will typically stabilize quickly at the lower temperature. At sub-ambient temperatures, the stresses in the seal are low and there is minimal structural degradation. Because the seal has experienced the high stresses and thermal degradation in the earlier high temperature condition, the seal may no longer be sufficiently elastic to maintain an acceptable sealing pressure at the sub-ambient temperature.

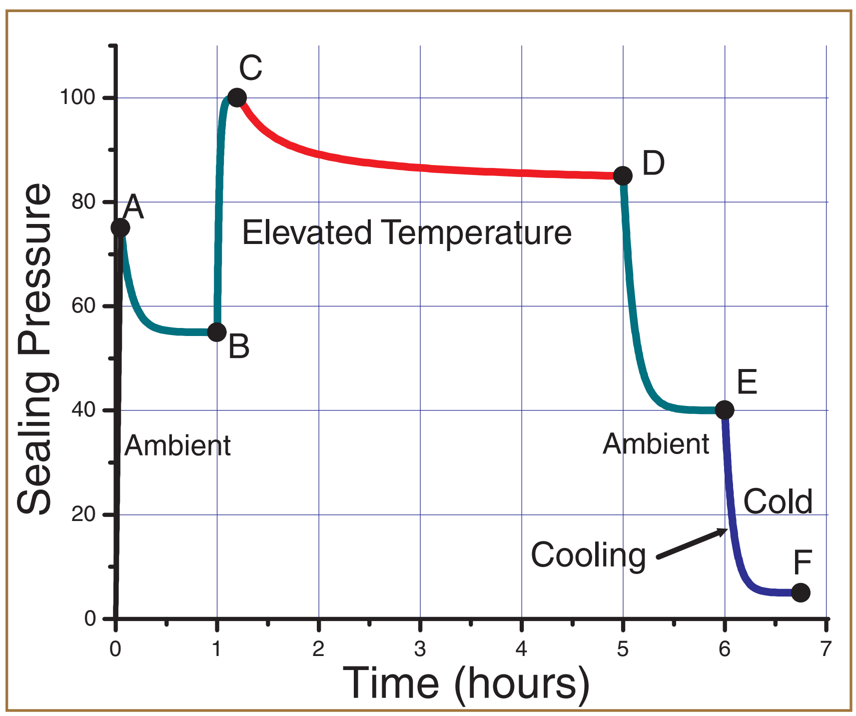

Figure 6, Additional Sealing Pressure Decrease (E. to F.) due to Thermal Contraction from Cooling

To understand the ability of the elastomer to perform at sub-ambient temperatures, it is therefore critical to first expose the seal to the highest temperature condition. The highest stress, the greatest degradation and the most vigorous chemical activity will occur during the highest temperature condition. The effects of the earlier high temperature condition become evident as reduced seal pressure during at the lowest temperature condition.

As an exercise, one could forgo the high temperature condition and proceed directly to the low temperature condition. After measuring the sealing pressure, one could then proceed to the highest temperature condition followed by a return to the low temperature condition. In this way, the total effect of the high temperature condition on low temperature sealing performance could be observed. It becomes readily apparent that experiments that measure low temperature elastomer properties without first experiencing the high temperature, constrained condition are of limited value in predicting elastomer seal behavior.

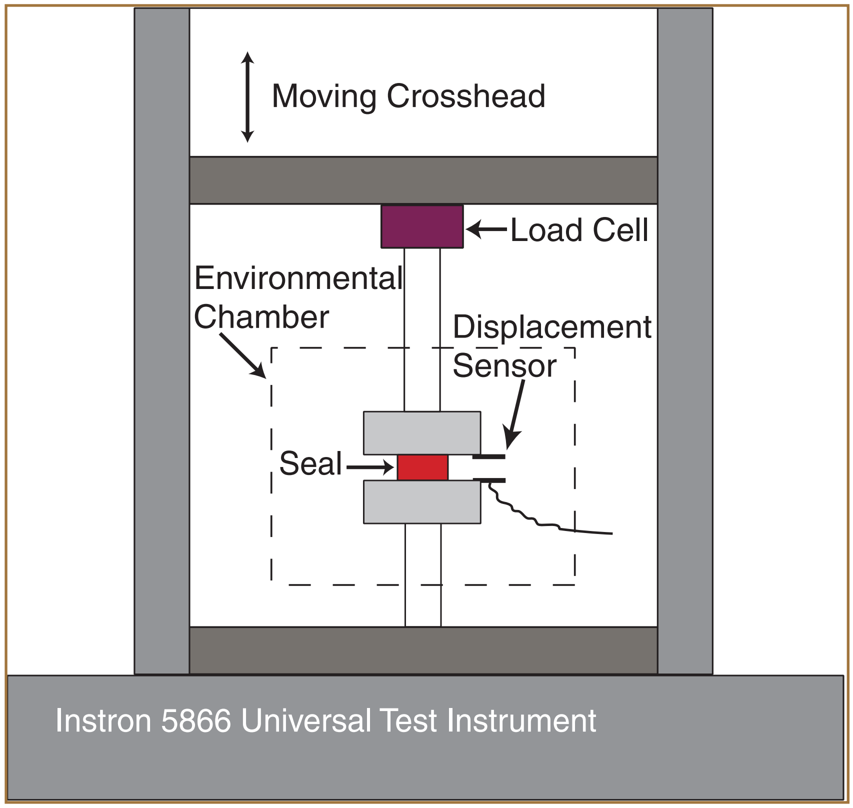

Figure 7, Schematic of Experimental Apparatus used to Measure Seal Pressure During Thermal Changes

Measuring the Effects of Temperature Changes in the Laboratory

The sequence described above can be performed in the laboratory on actual elastomer seals or on prospective seal materials. At Axel Products, an Instron 5800 Series universal test instrument capable of closed loop strain control is used. The seal is compressed between loading platens at ambient temperature. The seal is then held at this compressive strain while an environmental chamber is used to change the seal temperature. The measured properties are compressive force, time and temperature.

Although the idea is straightforward, the experimental difficulty lies in maintaining constant seal compression during temperature changes. Because the seal is typically small compared to the compression loading platens and the compression push rods that reach into the environmental chamber, the thermal expansion and contraction of the experimental apparatus may be more significant than the expansion and contraction of the seal. Therefore, the crosshead of the test instrument needs to move to accommodate the dimensional changes in the compression push rods and compression platens when the test temperature changes based on feedback from a displacement sensor at the seal gap. By doing so, very subtle changes in the seal pressures can be detected. A specially developed capacitive sensor is used to measure the gap between the platens and provide feedback control to the test instrument. A capacitive sensor is used because it is not affected by temperature changes.

An example of experimental data is shown in Figure 8. In the example, the seal softened dramatically when heated and at the coldest temperature the sealing pressure went to zero.

Comments and Observations

1. Understanding the effects of temperature changes on sealing pressure can be helpful in solving seal failures. In short, bad things happen when hot but do not become evident until cold.

2. Increasing seal compression by either using a thicker seal or by using a smaller seal gap will also cause higher maximum stress due to the increased confinement. Although this will increase the seal pressure at ambient temperature, it may result in increased structural degradation due to the higher maximum stress. This will then result in less elasticity and therefore lower sealing pressures at low temperatures. Without experimental data at varied seal conditions, it isn't obvious whether additional initial compression, less initial compression, a different material or seal re-design is needed.

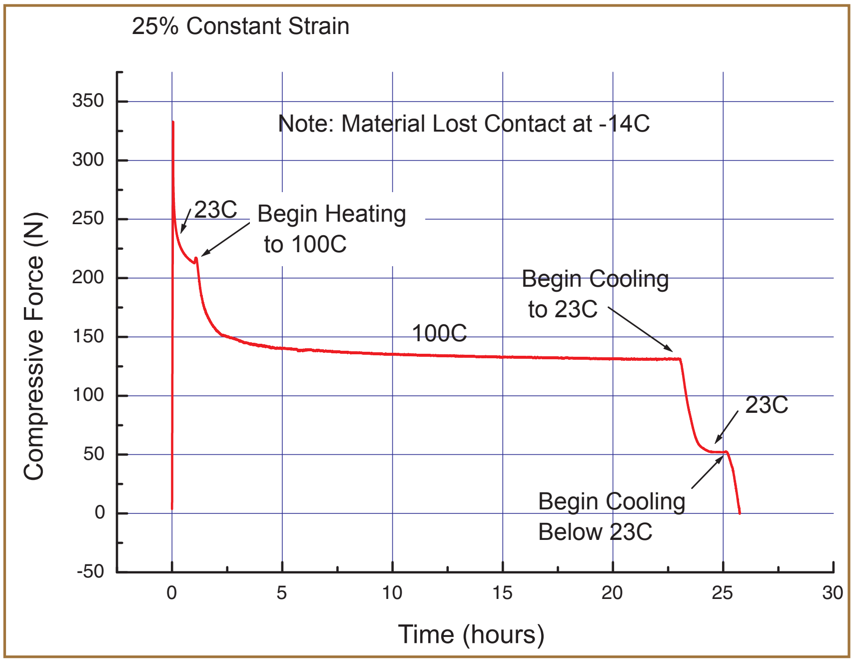

Figure 8, Example of Experimental Data showing an Elastomer Seal that Softened Significantly at Increased Temperature

3. Finite element analysis (FEA) is a powerful tool for the examination of stresses in elastomer seals. Often, this may be the only way to effectively optimize the shape of a seal to minimize localized stresses. However, FEA will not predict the degradation of material properties resulting from the high temperature, high stress event. This type of prediction is currently beyond the capabilities of standard "out of the box" material models.

For more information, visit www.axelproducts.com.

Axel Products provides physical testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics.

Data from the Axel laboratory is often used to develop material models in finite element analysis codes such as ABAQUS, MSC.Marc, ANSYS, Endurica and LS-Dyna.

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