TECHNICAL PAPER

"Choosing a high temperature steam resistant elastomer"

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Abstract:

The materials used to create seals must withstand, both physically and chemically, the extreme conditions in which they are increasingly being utilized. There are limited options for sealing with elastomers in hot water or steam environments in temperatures up to 550°F (288°C). Most elastomers in high temperature steam environments will become brittle and crack, resulting in leakage from a valve, pump or other equipment. Leakage resulting from a cracked seal can create hazardous conditions and ultimately, equipment failure. To avoid instances of failure and unnecessary downtime, due consideration must be given to the properties of the elastomer used in equipment sealing. This paper details the properties of the new EnDura® E90SR elastomer after high temperature steam exposure in comparison with other types of commercially available elastomers.

Introduction

An O-ring, or toroidal seal, is the most common type of seal used in the world today. Used to form a physical barrier to prevent the mixing of gases or liquid fluids, the simple toroidal shape of an O-ring has proven to offer high sealing efficiency across a wide range of applications. The sealing mechanism of an O-ring is a two stage process; compression and force. The initial compression (squeeze) upon the O-ring forms a physical barrier between the two fluids, forming the initial seal. It is therefore important to accurately control the amount of compression that the O-ring is subjected to. The elastomer acts like an incompressible viscous fluid with a high surface tension. When acted upon by a differential pressure, the O-ring translates this into force acting upon and normal to the mating surface. It is this force that forms the high pressure capability of the O-ring. It is important that the pressure can energise the O-ring to form this secondary sealing mechanism and hence free-space must be left in the groove, taking into account tolerance stack-ups and differential thermal expansion.

Discussion

The seal designer has to consider many factors such as temperature range, pressure and fluid environment in determining the optimal sealing material for an application.

- Temperature range of the application is the first factor that must be considered when choosing an elastomer. Low temperature decreases the flexibility of the elastomer and if the temperature is low enough the material will lose its elastomeric properties. The low temperature resistance of any elastomer is dependent upon the material's glass transition temperature. This is the temperature at which the elastomer changes from a rubber-like material to a brittle material. As an elastomer approaches its glass transition temperature, it would generally be expected that the tensile strength, hardness, modulus and compression set would all increase. High temperatures can increase crosslinking, in which the cross-link structure of the material tightens, causing a decrease in volume. The material can also become chemically altered under high temperatures, where an elastomer on initial exposure to elevated temperatures, may lose some process oils or low-molecular weight fragments of the polymer. In some applications, this loss of polymeric species may interfere with critical components or processes. Most often, elastomers will harden irreversibly in high temperatures and become brittle.

- Pressure within the application may cause mechanical extrusion of the seal, or if gases are present they will absorb into the elastomer, creating the potential for damage from rapid gas decompression. Permeation of a gas into an elastomer under high pressure may not result in any long term effect provided the pressure is released gradually, allowing the gas to slowly permeate out of the elastomer. However, if the pressure is released rapidly, the pressurized gas can expand suddenly, rupturing the elastomer in a catastrophic manner. Specific elastomer compounds are required to eliminate this effect.

- The fluid environment is critically important to seal selection. Fluid incompatibility can cause high volume swell in the seal. Though the volume increase in such instances may be reversible, the effects on the polymer may not be. Other effects resulting from incompatibility include embrittlement or softening, which are exaggerated or accelerated at elevated temperatures and can ultimately result in a seal failure.

In the case of hot water and steam, all three factors come into play. There is the high temperature, the water that can either swell the polymer or react with the polymer chemistry, and the pressure that cause low strength materials to extrude, or increases the risk of rapid gas decompression.

Sealing for oil and gas applications

Precision Polymer Engineering (PPE) has supplied high performance O-ring seals into the oilfield industry for more than 25 years. Specialist grades of elastomer are specifically tailored to meet the challenges of the most inhospitable operating environments in the world, such as high pressure, high temperature ultra-deepwater drilling and enhanced oil recovery. Sealing for high temperature steam resistance is particularly difficult as many high temperature elastomers do not maintain their properties. Selection of the correct elastomer for this type of application is therefore challenging, yet critical. By means of an overview, below is a selection of commercially available elastomers, and a summary of their properties and performance when deployed in high temperature steam environments:

Standard ethylene propylene (EPDM) elastomers

EPDM elastomers are well suited for water sealing applications and steam up to approximately 302°F (150°C), but will show property loss such as high volume swell, durometer loss, and cracking in higher temperature steam applications. As shown in Figure 1, a standard commodity EPDM elastomer O-ring is subjected to 316°C saturated steam. This O-ring exhibits a deformed shape, cracking and softening, which indicates incompatibility with the test conditions. If this seal was used in a valve or other application, there would likely be a leak or failure requiring downtime and repair.

Figure 1: Standard EPDM after 24 hours 316°C in steam. Specimen is warped with surface cracking.

Fluoroelastomers (FKMs)

FKMs are well known to resist high, dry temperatures and typically will retain properties up to 392°F (200°C). FKMs are generally considered high performance elastomers and often specified in equipment based on their high temperature capability in oil or fuels. However, critically, this compatibility does not extend to high temperature steam. In high temperature steam, FKMs become brittle and crack, which characteristically results in seal failure. As depicted in Figures 2 and 3, equipment using an FKM seal will experience leaks as the elastomer becomes brittle and cracks. In high temperature steam applications therefore, FKMs' are not appropriate.

Figure 2: FKM Terpolymer after 24 hours in 316°C steam.

Figure 3: FKM Copolymer after 24 hours in 316°C steam.

Nitrile butadiene rubber (NBR) and hydrogenated nitrile (HNBR) elastomers

NBR and HNBRs also become brittle after high temperature steam exposure, as depicted in Table 1.

Table 1: Material properties before and after steam exposure

	Units	HNBR	FKM Copolymer	FKM Terpolymer	FEPM	FFKM
Original values						
Hardness	IRHD	89	92	90	94	89
Ultimate tensile strength	MPa	32	16	24	25.4	28.9
Elongation @ break	%	264	120	210	123	86
Steam ageing: 168 hours @ 500°F						
Hardness	IRHD				88	82
Ultimate tensile strength	MPa		Brittle		16.5	27.5
Elongation @ break	%				129	86.8
Volume change	%				-5.6	-2.6

The limitations of the most common sealing materials creates an opportunity for new elastomers that will seal in applications such as geothermal wells, turbines, enhanced oil recovery and other situations where high temperature steam may be encountered. In each of these applications, reliability is critical for safety as well as for maximum efficiencies. High temperature steam and water resistant seals enable downhole tools to be utilized to improve well drilling and completion in geothermal wells, whereas downhole tools optimized for oil drilling may not survive the geothermal environment. Similarly, steam turbines operating at higher temperatures will be more efficient but require seals to withstand the operating conditions. Enhanced oil recovery is certainly an application where high temperature steam will challenge the sealing materials and benefit from the reliability of an elastomer specifically developed for the environment.

EnDura® E90SR

PPE has improved upon EPDM's resistance to hot water and saturated steam. PPE's research and development (R&D) laboratory studied existing elastomer materials to find, understand and define their limits. With a thorough knowledge of elastomer chemistry, PPE optimized the polymer, cure system and fillers to maximize steam resistance. The purpose for the development work was to create a best-in-class elastomer for steam resistance. This means not only improving upon the performance of EPDM, but improving the performance versus other high performance elastomers. The materials would also need to be in the 90 durometer range to resist extrusion at elevated temperatures and exhibit physical toughness by being resistant to rapid gas decompression. The R&D effort included a detailed search of scientific literature and numerous test compounds before a material was found to have the right balance of properties. The resulting material is known as EnDura® E90SR. Tests show that E90SR retains its properties at very high temperatures in steam at both 550°F (288°C) and 600°F (316°C), and has excellent resistance to rapid gas decompression. (See Table 2, and Figures 4, 5 and 6.)

Table 2: Steam ageing data at 550°F and 600°F for EnDura® E90SR

Ageing in steam: 168 hours, 550 F	**Units**	**Value**
Hardness, IRHD	Micro M	82
Ultimate tensile strength	MPa	16
Elongation at break	%	280
Volume change	%	8.2
Ageing in steam: 168 hours, 600°F		
Hardness, IRHD	Micro M	75
Ultimate tensile strength	MPa	4
Elongation at break	%	55
Volume change	%	12.6

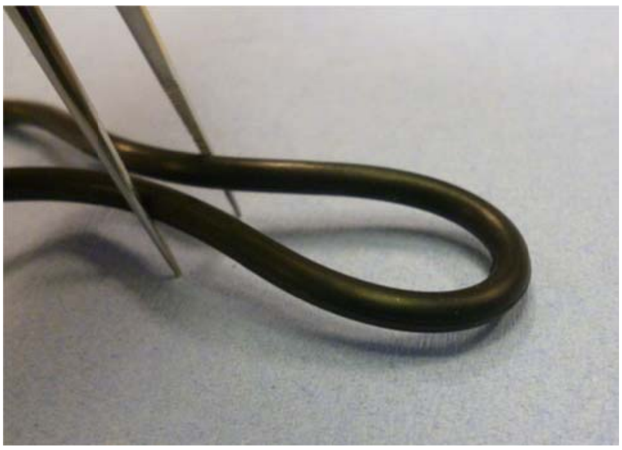

Figure 4: EnDura E90SR remains flexible without cracking in steam at 288°C for 168 hours.

Figure 5: Left is an unaged sample, right is a steam aged specimen at 288°C for 168 hours.

Figure 6: EnDura E90SR remains flexible without cracking in steam at 316°C for 24 hours.

Rapid gas decompression

Explosive decompression (ED) or rapid gas decompression (RGD) can occur when small gaseous molecules such as CO_2, methane or hydrogen sulfide are absorbed by the elastomer compound and then rapidly 'desorbed' when the high application pressure is released. Testing on ED resistant elastomer seals is carried out in pressurized housings, with different industry standards requiring a variety of gases, temperature ranges and decompression rates. By simulating actual field operation, independent testing can be carried out to confirm the performance of seal types and grades before installation. Testing was conducted to screen EnDura® E90SR against the NACE standard test method TM0297-97, which utilizes CO_2 as the test gas. A summary of the test conditions employed are shown in Table 3. Three E90SR O-rings were evaluated using NACE TM0297-97 Section 7.4, as shown in Table 4, and the results of the assessment are recorded in Table 5. The 10x optical micrographs illustrating the radial cross sections and surface of the O-rings are shown in Figure 7. **The E90SR O-rings were rated 1 according to** NACE TM0297-97 Section 7.4.

Table 3: Summary of NACE TM0297-97 test conditions	
Test conditions	
Temperature	120°C
Pressure	1000 psi
Gas	100% CO_2
Cycles	1
Conditions per cycle	
Soak period	24 hours
Depressurization rate	1000 psi min^{-1} (±10%)