Polymer Testing 58 (2017) 219–226

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Material Behaviour

Leakage behaviour of elastomer seals under dynamic unloading conditions at low temperatures

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ARTICLE INFO

Article history:
Received 5 October 2016
Accepted 15 December 2016
Available online 26 December 2016

Keywords:
Sealing material
Rubber
Partial release
Low temperature behaviour
Leakage rate

ABSTRACT

In technical applications, static seals are sometimes also subjected to dynamic loadings. Therefore, the leakage behaviour under dynamic conditions has to be evaluated as well. For this purpose, FKM elastomer seals have been tested by using newly designed equipment that allows for rapid partial release of the seal and simultaneous leakage rate measurement at a wide range of test temperatures. Furthermore, material characterisation was done by using Dynamic Mechanical Analysis, Differential Scanning Calorimetry and Compression Set. It was shown that, under static conditions, the leakage rate increased significantly during cooling at temperatures around 18 K lower than the glass transition range. On reheating, the seal's functionality was restored in the high temperature region of the glass rubber transition. In the subsequent dynamic release tests, that comprised a reduction of the seal compression within 1 s from 25% to 23%, increased leakage rates were observed in the high temperature region of the glass transition range. It was shown that the temperature that is critical for increased leakage is significantly lower under static conditions compared to dynamic conditions. The obtained leakage rates for static tests and dynamic release tests at different temperatures were analysed with reference to results of the material characterisation.

1. Introduction

For many technical applications, it is essential to separate two adjacent volumes and prevent the exchange of gasses, fluids or small particles. The machine elements used for this purpose are seals which serve as a barrier between volumes. These seals possess different geometries and designs, depending on the operating conditions of the application. One of the general differentiations can be made with reference to the load the seal experiences, thus distinguishing between dynamic and static seals. However, these classifications are not always strictly applicable, as static seals are often exposed to certain amounts of dynamic loads and vice versa.

The material that is used for seals has to meet different requirements which vary between applications. One of the most commonly used materials for seals are elastomers due to their high deformability and recovery [1]. Also, the material behaviour under chemical, thermal and mechanical loads is an important factor. Especially in safety relevant applications under extreme environmental conditions e.g. transportation of hazardous goods, information about the material behaviour at different operation temperatures and loadings is critical for reliable design choices.

The functionality of elastomer seals is affected by temperature in different ways. While high temperatures can lead to leakage due to decomposition, at low temperatures the rubber-glass transition (abbreviation: glass transition) leads to the most significant parameter changes that affect the functionality of the seal. At temperatures below the glass transition temperature the material becomes stiff and energy-elastic, thus losing its favoured characteristic as a sealing material.

One aspect of this transition is the reduced kinetic energy at decreased temperatures [2]. Any load that is applied to the elastomer in the entropy elastic state forces the material to undergo configurational changes that are not the most probable configuration [3]. Hence, the molecules are locked in the conformation they held while passing through the rubber glass transition temperature region or were forced to obtain during deformation [4].

Typically used methods for glass transition temperature detection are Dynamic Mechanical Analysis (DMA), which is based on the change in modulus of elasticity, as well as Differential Scanning Calorimetry (DSC) which uses the fact that the heat capacity

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http://dx.doi.org/10.1016/j.polymertesting.2016.12.018
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changes in the course of the glass transition.

However, the obtained temperatures for glass transition cannot easily be used for the reliable prognosis of component behaviour. It has been shown that predictions based on the transition temperatures are very conservative, therefore predicting the failure of a seal at temperatures much higher than observed in operation [5,6].

In order to make reliable design decisions which suffice safety concerns as well as economic restraints, it is advantageous to conduct component tests.

Weise et al. [5] investigated the leakage rates of elastomer seals at low temperatures and recorded the existing sealing forces. It was found that the failure of an elastomer seal, which is determined by a significantly increased leakage rate, only occurs at temperatures way below the glass transition range. On reheating, the functionality of the seal was restored.

Further investigations of the low temperature leakage behaviour of elastomer seals were conducted by Jaunich et al. [7,8]. For these tests, the seals were compressed between flanges and tempered at stepwise decreasing temperatures. At each temperature step, the leakage rate of the system was recorded by pressure rise measurements. Afterwards, the temperature was increased, also accompanied by leakage rate measurements at every temperature step.

On cooling, the results of Weise could be confirmed. A sudden increase in leakage rate could be observed at temperatures of about 10 K below the glass transition range determined by DMA measurements.

However, on reheating (in the second part of the experiment), the leakage rate stayed at a high value while passing through the previously determined failure temperature on cooling. The seal had to be heated up to the glass transition range to obtain the low leakage rate level of the beginning of the tests. Therefore, only when reaching the glass transition range was the seal's functionality restored completely.

However, the tests were performed under static compression, which might not cover real application conditions completely. Therefore, the investigation of the temperature dependent leakage behaviour under dynamic loading, such as a fast reduction of the degree of compression, is of special interest.

In Ref. [9] a device was introduced and described that allows for the investigation of leak tightness of elastomer seals under different compression ratios, loadings and temperatures. Additionally, for verification of the device's usability, first results were presented. These involved the temperature dependent leakage behaviour of a seal under static conditions as well as the critical temperatures that lead to failure under dynamic release conditions.

The tests under dynamic release conditions increase knowledge about general seal behaviour. In addition, they bear a close resemblance to many seal applications where even static seals can be subjected to dynamic loads and accelerations, e.g. under accident conditions for containers.

In this paper, data that was gained with the new testing equipment is evaluated in detail. This involves analysis of different material characterisation methods which are then put into context with the experimental data. A correlation between seal recovery kinetic measured by Compression Set (CS) and the leakage behaviour is performed. Additionally, the seal behaviour after forced recompression is addressed. This extends the approach of understanding to possible accidental events taking place during operation.

2. Test equipment and procedure

For the investigation of the behaviour of elastomer seals under dynamic loads, a specially designed device was used, which is shown in Fig. 1. A detailed description of the device and first results can be found in Ref. [9].

The test setup consists of a flange system, parts for mounting purposes and a mechanical device that makes it possible to apply additional compression force or remove it to perform a partial release. The flanges are placed inside a temperature chamber to set the seal to a defined test temperature while simultaneously recording the leakage rate via pressure rise measurements. A detailed description is given in Ref. [9].

For the evaluation of the leakage behaviour, the leakage rate of the system is measured. The leakage rate is a value that is dependent on the number of particles passing a gap between two volumes within a specific period of time. It is usually defined by the change in pressure Δp in a volume V over a period of time Δt. From these factors, the leakage rate Q can be derived as shown in Equation (1).

$$Q = \frac{\Delta p \cdot V}{\Delta t} \tag{1}$$

The sealing performance of the specimen was tested under static and dynamic conditions beginning at room temperature. Then measurements were conducted at stepwise decreased temperatures which, in the case of static tests, were followed by stepwise reheating.

The static testing procedure for each test temperature is as follows: At first the seal was compressed to the higher of the two possible degrees of compression, e.g. 25%. The volume V was then determined by adding a known amount of ambient air to the evacuated device. By recording the resulting pressure rise, the inner volume of the device can be calculated.

After that, the actual pressure rise measurement for the determination of the leakage rate was executed. Therefore, the pressure in the evacuated inner volume was measured over a time period of 60 min or until it rose more than 20 mbar above the start pressure. With this approach, the measuring accuracy of the sensor is taken into account and noise is reduced.

The measurement of the leakage behaviour under dynamic release was performed in a similar manner. In contrast to the static tests, however, a rapid partial release was executed by loosening the nut directly before the start of the pressure rise measurement.

Additionally, the testing of the leakage rate after recompression can be performed. For this purpose, after a test with partial release, the temperature was kept unchanged and the nut retightened. Then, a test procedure equivalent to the static tests was conducted.

3. Material and characterisation methods

The specimen used for the component tests were commercial FKM O-ring seals with a diameter of 180 mm and a cord thickness of

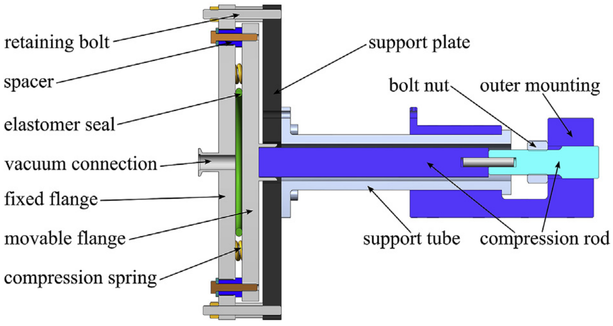

Fig. 1. Cross sectional view of test setup [9].