Polymer Testing 65 (2018) 134–141

Contents lists available at ScienceDirect

Polymer Testing

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

Test Method

Application of digital image correlation technique to evaluate creep degradation of sealing elastomers due to exposure to fluids

Leonardo Israel Farfán-Cabrera[a,*], Juan Benito Pascual-Francisco[b], Ezequiel Alberto Gallardo-Hernández[c], Orlando Susarrey-Huerta[b]

[a] Universidad Tecnológica de México, UNITEC MÉXICO, Campus Cuitláhuac, México City, C.P. 02870, Mexico
[b] Instituto Politécnico Nacional, SEPI-ESIME, Unidad Zacatenco, IPN, Grupo de Mecánica Fractal, Col. Lindavista, México City, C.P. 07738, Mexico
[c] Instituto Politécnico Nacional, SEPI-ESIME, Unidad Zacatenco, IPN, Grupo de Tribología, Col. Lindavista, México City, C.P. 07738, Mexico

ARTICLE INFO

Keywords:
Elastomers
Creep
Digital image correlation
Rubber
Degradation

ABSTRACT

This work aims to evaluate degradation of viscoelasticity in terms of creep of four sealing elastomers (flouroelastomer/Viton A®, silicon rubber/vinyl-methyl silicone, chloroprene rubber and ethylene-propylene-diene monomer) upon exposure to engine lubricant and diesel by using digital image correlation technique in a creep experiment for determination of changes in creep behavior of elastomers. Short creep experiments (3 h) were conducted under a tensile load of 1.5N before and after the immersion in the fluids. Also, standard compatibility tests were simultaneously conducted to determine changes in mass, volume, tensile and tearing strengths, and hardness to extend the degradation study. Hence, the creep compliance behavior of the samples was successfully obtained and the creep degradation due to immersion tests was determined. It was found that this alternative method for evaluation of creep degradation of elastomers is very suitable and useful since very low complexity and strain measurement accuracy.

1. Introduction

Polymers experience chemical and physical degradation by different mechanisms, which are related to their composition and exposure conditions. Commonly, such degradation can be determined in terms of physical changes, such as: mechanical, electrical and aesthetic properties [1]. Depending on the application of the polymers, such properties take certain importance to prevent or control failures. In particular, polymers used in mechanical applications are mostly expected to present minimal changes in mechanical and aesthetic properties. However, in some cases, reaching minimal degradation of polymers is difficult because the applications involve a wide range of working conditions, including, operation at high or low temperatures, exposure to ultraviolet radiation and different chemical media, fatigue, corrosion, etc.

Particularly, elastomers are polymers widely employed as seals for machinery since they present relative good softness and compliance, good resistance to abrasion, impermeability, and resistance to different chemical media, which are requirements for a good sealing performance. In general, seals are divided into static and dynamic [2]. The former are employed to seal joints in static conditions while the second are used to prevent or limit leakages by allowing the free movement of dynamic shafts. Mainly, the degradation of seals is caused by their exposure to aggressive chemical fluids, namely, combustibles, mineral and synthetic oils (lubricants), anti-coolants, acids, corrosive water, hydraulic fluids, etc. Thus, any intended use of elastomers in a specific application must comprise the study of degradation caused by the interaction with the involved fluid in particular conditions; this study is termed as compatibility. The standard methods ASTM-D471, ASTM-D7216, and ASTM-D4289 are examples of procedures specified to determine the compatibility of elastomers with fluids in different conditions. Basically, the procedures consist on conducting immersion tests in a range of test conditions. The changes of their physical properties caused by a certain immersion period are measured to rate degradation and compatibility. The physical properties to be evaluated are mass, volume, hardness, tensile and tear strength, elongation, breaking resistance, burst strength and adhesion for coated fabrics. In general, the results show a valuable overview of the degradation of the elastomers, however, complementary assessment of other particular properties should be considered to extend the prediction of service life and performance. In the case of sealing materials, the viscoelastic behavior is a very important factor to be considered since it rules the contact mechanics at the sealing interfaces having effect on the sealing performance. Owing to viscoelasticity involves and combines viscosity and elasticity properties, the strain-stress behavior is time and temperature

* Corresponding author.
E-mail address: farfanl@hotmail.com (L.I. Farfán-Cabrera).

https://doi.org/10.1016/j.polymertesting.2017.11.017
Received 30 August 2017; Received in revised form 10 November 2017; Accepted 13 November 2017
Available online 17 November 2017
0142-9418/

Abbreviations

ASTM-D2240 Standard test method for rubber property—durometer hardness
ASTM-D2990 Standard test methods for tensile, compressive, and flexural creep and creep-rupture of plastics
ASTM-D412 Standard test methods for vulcanized rubber and thermoplastic elastomers—tension
ASTM-D4289 Standard test method for elastomer compatibility of lubricating greases and fluids
ASTM-D471 Standard test method for rubber property—effect of liquids
ASTM-D624 Standard test method for tear strength of conventional vulcanized rubber and thermoplastic elastomers
ASTM-D7216 Standard test method for determining automotive engine oil compatibility with typical seal elastomers
CR Chloroprene rubber
DIC Digital Image Correlation
DMA Dynamic Mechanical Analysis
EPDM Ethylene-Propylene-Diene Monomer
FKM Flouroelastomer/Viton A®
VMQ Silicon rubber/Vinyl-Methyl silicone

dependent, so, the assessment of such property can become a complex matter.

Theoretically, the time dependent behavior of materials under a quasi-static state at a constant temperature may be characterized by means of creep compliance [2]. It is a viscoelastic property, which means a slow continuous deformation with time, $\varepsilon(t)$, of a material under constant stress, σ_o, which may be expressed by the equation:

$$J(t) = \frac{\varepsilon(t)}{\sigma_o} \quad (1)$$

This property may be experimentally obtained by applying a constant tensile or compressive load to a specimen in order to generate a constant stress while the strain occurred with time is measured. The standard procedure ASTM-D2990 covers the determination of creep and creep-rupture of plastics under tensile and compressive stresses at specific environmental conditions. However, the attempts to develop a precision and bias statement for these test method have not been successful, which is a limitation to surely add this method to the standard compatibility study. Thus, some alternative tests have been investigated and proposed to determine the creep compliance of elastomers, such as: dynamic-mechanical analysis (DMA) [3], non-standard tensile tests [4], measurements via nanoindentation test [5,6], and optical measuring techniques incorporated into indentation tests using axi-symmetric indenters [7–10]. The acquiring and accuracy of the creep results from each test are straightly related to the complexity of the creep experiment and the strain measurement technique employed since this property is commonly evaluated through considerable long periods of stressing. Currently, in order to enhance the accuracy of the strain measurements, non-contact measurement methods (optical methods) have developed and implemented positively. In particular, digital image correlation (DIC) has been extensively validated and used as a powerful and flexible tool for the strain measurement of a wide range of materials, including elastomers [11–14] since it presents less stringent requirements than other optical techniques such as the interferometric techniques under different experimental conditions [15]. Fundamentally, DIC is an optical metrology based on digital image processing and numerical computing, providing full-field displacements and strains by comparing the digital images of the specimen's surface in the undeformed and deformed states, respectively [16]. Thus, the DIC software recognizes a light intensity pattern of a small area along the undeformed image finding the same area in the deformed image, as well as one or several points on the surface.

The present work is focused on evaluating the physical degradation in terms of creep compliance of four elastomers due to the exposure to a lubricant (engine mineral oil) and a combustible (diesel), respectively, by using the DIC technique for the strain measurement in a simple creep experiment. The test was initially conducted for 1 min and then continued till 3 h. Also, standard compatibility tests based on the ASTM-D471 method were simultaneously carried out for comparison and support for the understanding of degradation of other physical properties, such as: changes in mass, volume, tensile and tearing strength, and hardness. Finally, the viscoelastic degradation in terms of creep compliance of the samples was observed by the analyses carried out by using the supplementary DIC test set-up.

2. Experimental details

2.1. Compatibility standard test

The standard method ASTM-D471 was carried out to determine the compatibility overview of four sealing elastomers with two fluids, namely, a lubricant (commercial engine mineral oil) SAE 15W-40 and diesel. The four elastomers selected were flouroelastomer/Viton A® (FKM), silicon rubber/vinyl-methyl silicone (VMQ), chloroprene rubber (CR) and ethylene-propylene-diene monomer (EPDM), which are widely used as static and/or dynamic sealing materials for machinery [17]. Hence, the elastomeric samples were subjected to static immersion tests at a temperature of 24 ± 1 °C for 670 h. The physical degradation was assessed by measuring the changes in mass, volume, tensile and tear strength, and hardness caused by the exposure to the fluids. Specimens with particular geometry characteristics were prepared to conduct each test; in Fig. 1, examples of the specimens used can be seen. The mass changes were measured by using a balance with a 0.1 mg of accuracy while the volume changes were estimated by measuring the dimensions of the samples with a precision caliper gauge. The tensile and tear strengths were measured with a tensile tester having a load cell of 900 N. The tensile strength was measured in specimens with dumbbell shape having a gauge length of 30 ± 1 mm by following the ASTM-D412 method at a strain rate of 50 mm/min. On the other hand, the tear strength was measured according to the ASTM-D624 method on "T" type specimens at a separation rate of 50 mm/min. The hardness measurements were performed according to the ASTM-

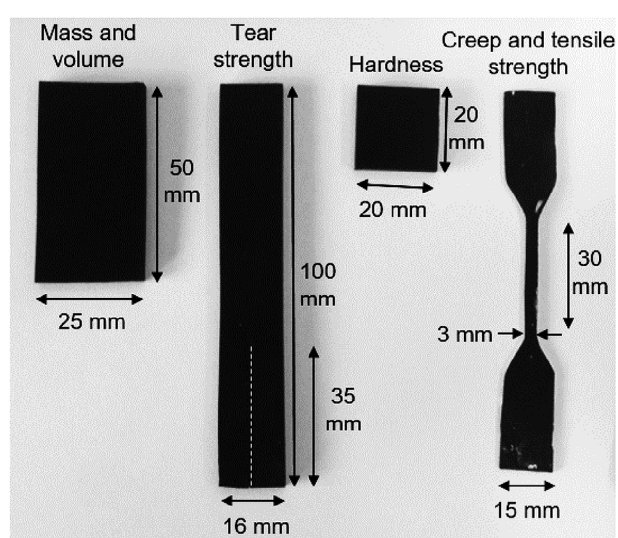

Fig. 1. Examples of the specimens used for the different tests.