



Test Method

Determination of creep compliance, recovery and Poisson's ratio of elastomers by means of digital image correlation (DIC)



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ABSTRACT

This work aims to determine the creep compliance, creep recovery and Poisson's ratio of three common sealing elastomers by means of the digital image correlation (DIC). The tests were conducted by stressing specimens under three different constant stresses during short duration experiments (3 h) to see the prospective of DIC for this application. The strains were measured in x and y axes with time. Thus, the behavior of creep compliance, creep recovery, and the Poisson's ratio of each elastomer were obtained. The creep results exhibited repeatability, as well as, the mean Poisson's ratios estimated were close to reported values for elastomers. Finally, despite of some limitations from the DIC equipment, it was found that this procedure can be implemented as a suitable alternative for the characterization of creep compliance, creep recovery and Poisson's ratio of elastomers. Also, it may be enhanced by following some recommendations given.

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1. Introduction

In industry, elastomers are widely used to manufacture static and dynamic seals because of their good softness and compliance, which are necessary to produce a fit interface with the counterfaces [1]. The ideal sealing performance could be achieved by keeping constant contact pressure between seals and counterfaces through their entire service life. However, elastomers are not completely elastic materials since they exhibit viscoelastic behavior. Viscoelasticity comprises and combines both elasticity and viscosity properties, so the strain-stress behavior is time and temperature dependent, which is the cause of the non-constant contact pressure produced at the sealing interfaces. Basically, the time dependent behavior of materials under a quasi-static state may be characterized by means of creep compliance [2]. Creep compliance is a material property, which means a slow continuous deformation, $\epsilon(t)$, of a material under constant stress, σ_0 , so this property may be expressed by the equation:

$$J(t) = \frac{\epsilon(t)}{\sigma_0} \quad (1)$$

In order to obtain the creep behavior of elastomers, some experimental tests have been developed, such as: the standard methods: ASTM-D2990 and ISO 899-1:2003, non-standardized tensile tests [3], dynamic-mechanical analysis (DMA) [4], nano-indentation measurements [5,6], and indentation tests using axisymmetric indenters by means of optical techniques [7–10]. In particular, each method exhibits limitations and considerations derived from the tester configuration and the accuracy of the strain measurement technique employed. In general, the widely used strain gauge technique and the non-contact optical methods (interferometric and non-interferometric) have been developed and validated to measure the surface deformation of materials. Interferometric techniques comprise the holography interferometry, speckle interferometry and moiré interferometry while the non-interferometric techniques involve the grid method and digital image correlation (DIC). Both optical methods present high accuracy for strain measurement, however, the non-interferometric techniques are less accurate than those interferometric, however, they present less stringent requirements under different experimental conditions [11]. DIC method, in particular, has been

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extensively validated and used as a powerful and flexible tool for the strain measurement of a wide range of materials. Also, it presents effectiveness for measurement of large strains in contrast to the interferometric techniques. Basically, it provides full-field displacements and strains by comparing the digital images of the specimen's surface in the undeformed and deformed states, respectively. In previous research works, DIC has already been utilized to measure strains generated in elastomers by conducting tensile tests in order to determine the stress-strain behavior, exhibiting accurate and reliable results [12–14]. Hence, DIC may be also positively implemented for the strain measurement in terms of creep compliance of elastomers to determine their viscoelastic behavior.

DIC is a whole field optical metrology based on digital image processing and numerical computing by the recognition of one or several points on the surface, as well as the gray level of a small area along the undeformed image finding the same area in the deformed image [15], which differentiates DIC from other full field measurements methods and in particular from the grid method and interferometric methods. Typically, DIC uses one or two black and white charged coupled devices (CCD) type camera to acquire the images, where 256 levels of grayscale are used for the digitization of the light intensity in the black and white image [16]. In particular, image dynamics (256 levels of grayscale) correspond to a dynamics of 8-bit cameras. However, a DIC software can be capable of processing images with different dynamics. Any point in the undeformed image is defined by the value of the gray level from the surrounding area. The identical point in the deformed image is identified by finding a point with an identical intensity pattern in the surrounding area from the original point. In practice, a black and white speckled pattern is employed to represent the grey level. For surface deformations, the mapping function concerning the images can be derived from comparing a set of sub-window pairs over the whole images, as it is seen in Fig. 1. Thus, the grid points $Q(x_2, y_2)$ and $Q'(x_2', y_2')$ are associated with the translations and transformations occurred between the two images [16]; this is:

$$x_2' = x_1 + u + \frac{\partial u}{\partial x} \Delta x + \frac{\partial u}{\partial y} \Delta y \quad (2)$$

$$y_2' = y_1 + v + \frac{\partial v}{\partial y} \Delta y + \frac{\partial v}{\partial x} \Delta x \quad (3)$$

where u and v are displacements of the point P in x and y direction, respectively. Hence, $\frac{\partial u}{\partial x}$ and $\frac{\partial v}{\partial y}$ represent the strains ϵ_x and ϵ_y , respectively. So, the creep compliance expressed by Eq. (1) can be obtained using the strains in y axis, ϵ_y , from the digital image processing. In addition, the Poisson's ratio may be also obtained from the displacements occurred in both y and x axes at the same instant, being estimated by the equation:

$$\nu = -\frac{\epsilon_x(t)}{\epsilon_y(t)} \quad (4)$$

According to the idealized creep behavior for elastomers [2] (see Fig. 2a), the creep curve consists of three stages: The former is the primary region, which is the early stage of loading when the creep rate rapidly decreases with time. The initial strain can involve both elastic and plastic deformations, which are instantaneously generated after the stress occurred. Afterwards, the secondary creep stage corresponding to the steady state is followed. Then a rapid increase and fracture are produced, which correspond to the tertiary stage. The last region is commonly seen in testing of ductile materials subjected to high stresses. On the other hand, in Fig. 2b, the curve represents the idealized creep recovery behavior for

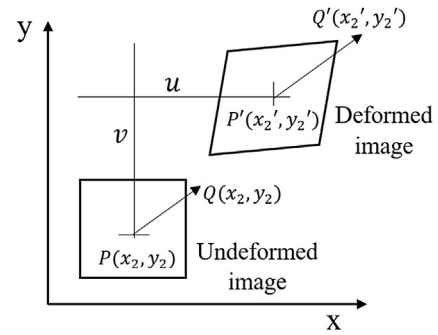


Fig. 1. Theoretical relationship of undeformed and deformed images.

viscoelastic materials, which is obtained by releasing the stress at the secondary stage. It can represent the trend of strain recovery with time and the plastic deformations occurred.

The paper presents the determination of the behavior of creep compliance and creep strain recovery, as well as the Poisson's ratio of three elastomers by using the technique of digital image correlation (DIC). The tests involved the stretching of specimens in form of dumbbell shape by applying dead weights to achieve constant stresses while the strains were measured with time by means of DIC.

2. Experimental details

2.1. Testing set-up

In Fig. 3, the creep testing set-up is seen. Basically, the test specimen is gripped in the top by using the specimen holder, which is mounted on a precision loading frame. When the test starts, the load is gently and manually applied to the bottom via dead weight. The weight is gripped to the specimen by using a blinder clip to produce axial strength. It produces a constant stress on the specimen, which is required for the creep test. A white light source is used to illuminate the specimen. Moreover, in order to measure the strains generated by the stress, the DIC equipment (Dantec Dynamics Q-450 system) was employed. It consists of two CCD cameras with color depth of 8, 10, 12 and 14 bits with a shooting speed in the range of 1 frame each 5 s to 10000 frames per second. They are mounted on a high precision tripod. The cameras are connected to a computer in order to log the images taken by the cameras in real time. The software Istra 4D is incorporated to the computer to configure and synchronize the function of both cameras (shooting speed and amount of frames to be logged) with the computer operation, as well as to posteriorly perform the data analysis (digital image correlation) [17]. For this study, the cameras were configured to work with color depth of 8 bits, so 256 levels of greyscale were used. In the equipment, the lenses (Carl Zeiss, Makro-planar 2/50 ZF) with aperture of 2–25 mm and an optical zoom of 0.24–5 m were used. The sensor CCD size is 18.76×13.8 mm having a full resolution of 1632×1200 pixels. The image processing was performed according to the default configuration of the software, having a window size of 7 pixels and a correlation accuracy of 0.1 pixels. These experiments can be similarly conducted by only using one camera, however, the use of two cameras enables to simultaneously measure the strains occurred in three directions, namely, x , y , z , which may be useful to analyze the strains in specimens with complex geometries.

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