Polymer Testing 58 (2017) 270–279

Contents lists available at ScienceDirect

Polymer Testing

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

Property Modelling

Silicone gels - comparison by derivation of material model parameters

G. Previati*, M. Gobbi, G. Mastinu

Dept. of Mechanical Engineering – Politecnico di Milano, Italy

ARTICLE INFO

Article history:
Received 22 November 2016
Accepted 9 January 2017
Available online 10 January 2017

ABSTRACT

The mechanical properties of three different silicone gels were characterized by means of tension, shear and compression tests at large deformations. The non-linear behavior of the materials is taken into account and three material models (Neo-Hook, Yeoh, Ogden) for rubber-like materials have been considered in order to assess their capability to describe the behavior of the gels. The parameters of the material models are reported.

1. Introduction

Inorganic and organic-inorganic gels are widely used in many applications [14] [15] [17] because of their low thermal conductivity, optical characteristics, low density and high damping [22]. Developments in the material compositions, mostly by adding organic components [17] [25], have improved their mechanical properties, and strains of over 80% can be reached [22]. For these gels, load-bearing applications can be considered [16] [19].

The mechanical properties of gels have been investigated by many authors from the practical and the theoretical points of view. Mechanical properties, such as Young's modulus and Poisson's ratio [18] [21] and mechanical strength [21], are used to compare different manufacturing techniques, process technologies and aging [20].

Many different test methods for the measurement of the mechanical properties of gels can be found in the literature [18] [22]. Three-point bending [20] [22] [24] [27], compression tests [19] [21] [26], indentation techniques [19] [23] and sonic waves [19] are generally used to measure the elastic modulus of a gel. Tension and shear tests can also be used [19], especially for non-brittle gels.

Given the wide range of insulation applications, the vibrational behavior of this material is widely investigated and the complex elastic modulus is measured by dynamic tests, mostly dynamic three point bending and compression tests [22].

Many of the considered papers deal with small deformations of the gels. In Ref. [19] the strain-stress relationship for a tension test up to 15% of deformation is considered to evaluate the effect of process parameters and fiber reinforcement. The behavior of gels at large deformations seems similar to the behavior of rubber-like materials (see for instance [19] [28]). For some gels, incompressible behavior can be assumed [20], in other cases, Poisson's moduli of the order of 0.3 can be found [18].

The use of gels in applications where large deformations are reached requires knowledge of the material behavior in the non linear region of the stress strain curve. Moreover, a material model able to describe this behavior is required for computations.

In this paper, three different material models developed for rubber-like material are investigated in order to highlight their applicability to silicone gels at large deformations. Both incompressible and compressible material behavior has been considered.

The three silicone gels are named by their producer θ_5, β_{GE}, and NP_{GEL} [30–32]. They have been characterized by means of tension, shear and compression tests at large deformations. The proposed tests have been used to quickly characterize the materials with a very simple experimental setup.

2. Tested materials

Materials A and B are organic-inorganic composites containing silicone and unspecified inorganic additives, material C is a silicone-based foam (see Refs. [30–32]). Fig. 1 shows the three considered materials.

3. Experiments

The three considered materials were tested by means of tension, compression and shear tests. The tests were performed on a MTS series 150 test machine. For all of the three tests, the applied load was measured by means of a single-axis load cell (full scale 20 N or

* Corresponding author.
E-mail address: giorgio.previati@polimi.it (G. Previati).

http://dx.doi.org/10.1016/j.polymertesting.2017.01.011
0142-9418/

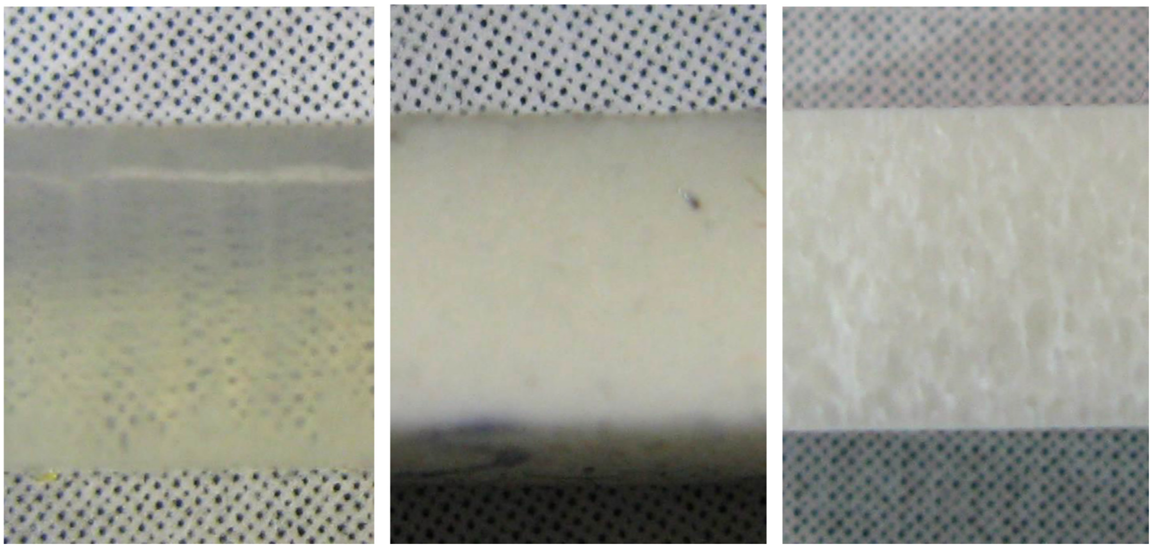

Fig. 1. Tested materials. Left: material A. Middle: material B. Right: material C.

1 KN depending on the maximum applied force).

The tension tests were performed in general accordance with ISO 37 [9] for rubber materials. The maximum stretch has been set to 1.75 for materials A and B and to 1.5 for material C. Such levels of stretch were the maximum level that the materials could survive in order to get the full loading-unloading curve. Three specimen have been tested for each material. Each specimen has been preconditioned with five loading-unloading cycles before the test. The test speed was 4 mm/min to avoid relevant viscous effects. Given the low stiffness of the material, to overcome the problem of measuring large displacements [19], an optical method has been considered. A grid has been plotted on the specimen and then the test video has been recorded by means of a high definition camera (resolution 720 × 576 pixel, 5 fps). The displacements were computed during post-processing by tracking the deformation of the grid on the specimen during the test. Fig. 2 shows a specimen of material A during the tension test. The straight part of the specimen has a length of 33 mm and is 6 mm wide. The thickness of the specimen is 5 mm for materials A and B and 6 mm for material C. Such dimensions exceed the standard and are due to the commercial packaging of the material. The specimens were obtained by a cutting technique. Three specimens were used for each material.

The compression test was performed in general accordance with ISO 7743 [10]. Given the low stiffness of the tested materials, the displacement has been considered equal to the displacement of the crossbeam of the testing machine. The two surfaces of each specimen were glued to an aluminum disk. In this way, the boundary conditions at the interface of the specimen are well known. The resulting state of stress is multi-axial and the effect of the compressibility of the material can be observed. The thickness of the specimens was set to 5 mm for materials A and B and to 6 mm for materials C. This thickness is much lower than the thickness suggested by the standards and it is due to the commercial packaging of the materials.

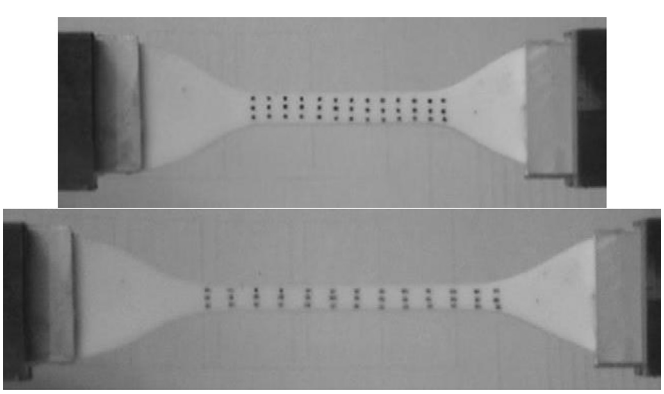

Fig. 2. Specimen of material B during the traction test. Top: stretch = 1. Bottom: stretch = 1.75.

The shear test was performed in general accordance with ISO 1827 [11]. As in the previous case, given the low stiffness of the tested materials, the displacement was considered equal to the displacement of the crossbar of the testing machine. The dimensions of the specimens are reported in Fig. 3. The thicknesses of the specimens for materials A and B are equal to 5 mm and comply with the standard, while the thickness of the specimens for material C is 6 mm, slightly exceeding the standard.

4. Material models

For each considered material, three well-known models developed for rubber materials were chosen.

The material models are obviously defined in the framework of continuum mechanics [2] [3] [4]. The deformation of a body can be described by means of the deformation gradient **F** ($F_{ij}=\partial x_i/\partial X_j$,, X_j and x_i being the coordinates of a point in the undeformed and deformed reference frames respectively). The right Cauchy-Green deformation tensors **C** can be defined as

$$\mathbf{C} = \mathbf{F}^T\mathbf{F} \tag{1}$$

It is worth noting that $det(\mathbf{C})=\det(\mathbf{F})^2=J^2$ where J is the volume change. For the definition of material models, the invariants I_1, I_2 and I_3 of **C** play a very important role [2].

$$I_1 = tr(\mathbf{C}) = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \tag{2}$$

$$I_2 = \frac{1}{2}\left(tr(\mathbf{C})^2 - tr\left(\mathbf{C}^2\right)\right) = \lambda_1^2\lambda_2^2 + \lambda_1^2\lambda_3^2 + \lambda_2^2\lambda_3^2 \tag{3}$$