Applied Radiation and Isotopes 70 (2012) 823–826

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

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

A novel method to determine Poisson's ratio by beta-ray absorption experiment

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ARTICLE INFO

Article history:
Received 7 November 2010
Received in revised form
22 December 2011
Accepted 23 January 2012
Available online 9 February 2012

Keywords:
Beta absorption
Thickness measurement
Poisson's ratio

ABSTRACT

In this paper a new experimental method is applied to determine Poisson's ratio of an industrial rubber tape based on the attenuation of beta particles. A simple theoretical model is presented and the experimental results are compared with the model's prediction. Poisson's ratio of the rubber is obtained by applying a steady state strain force. The relatively good agreement between the model's prediction and the experimental results could be a verification test for the presented method.

1. Introduction

The elastic properties of materials are very important in both scientific and technical aspects. They describe the mechanical behavior of materials and their measurement is very important from the material science and engineering point of view. The choice of an appropriate material for particular application requires the knowledge of its mechanical properties and parameters such as elasticity coefficient, Young's modulus and Poisson's ratio (Cross, 2008).

This information is fundamentally important in interpreting and understanding the nature of bonding in the solid state. Hence these parameters are needed for determining design criteria in order to avoid in-service failure of a mechanical component. Poisson's ratio is one of the mechanical parameters which are required to fully describe the elastic property of the material. Poisson's ratio is defined as the ratio of the negative of transverse strain to the strain in the longitudinal direction. It is also a measure of material's relative resistance to dilatation and shearing (Roy and Mollenhauer, 1994). It has a value between 0 and +0.5 depending on the compressibility of the material. For elastomeric materials, which have high bulk modulus relative to Young's modulus, Poisson's ratio is about 0.5.

Measurements of Poisson's ratio can be divided into four groups:

- Static measurements (time-independent) of the equilibrium Poisson's ratio for both anisotropic (Holownia, 1975; Wilson and Ladizesky, 1976) and isotropic materials (Laufer et al., 2004; Fedors and Hong, 1982).
- Time dependent measurements of Poisson's ratio for anisotropic materials (Darlington et al., 1977; Richardson and Ward, 1978).
- Temperature dependent measurements of Poisson's ratio for homogeneous isotropic materials by (a) direct (Gilmour et al., 1979) and (b) indirect methods (Crowson and Arridge, 1979 a,b; Burguete et al., 2004).
- Frequency dependent measurements of Poisson's ratio on homogeneous isotropic materials by (a) direct (Lin and Yee, 1992) and (b) indirect methods (Thomson, 1966).

The fact that the bulk modulus and Poisson's ratio are also time-dependent and is not fully appreciated. In fact, they are often assumed to be time-independent constants. Measurement of the elastic constants is a necessary but not an easy task. Poisson's ratio is in many instances the most troublesome elastic parameter to determine. Several methods have been developed to determine Poisson's ratio and these can be classified as mechanical (Vijgen and Dautzenberg, 1995), ultrasonic (Lindblad and Fürst, 2001; Xie et al., 2005) and optical (Kartalopoulos and Raftopoulos, 1978; Gentle and Halsall, 1982).

In this paper a new experimental method based on the beta absorption principle is presented to calculate Poisson's ratio. Also a new theoretical explanation is described. This report is concerned with the measurement of the time-dependent Poisson's ratio of viscoelastic materials in the transition region. The proposed method determines Poisson's ratio using the results of typical procedures including the definition of physical properties, such as Young's modulus.

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doi:10.1016/j.apradiso.2012.01.020

2. Theory

When a beam of beta particles with an initial intensity I_0 encounters with a sample target, electrons are scattered by atoms in the sample. As a result, the intensity of the initial beam reduces exponentially. The μ coefficient, which describes the absorption rate in the sample material, is related to the density of material, n, and interaction cross section, σ, between beta particles and atoms of the sample. In most cases the μ coefficient is obtained by experiment. Here we try to measure the thickness of the test material by utilizing beta particles. The experiment includes the measurement of the thickness of a specimen by irradiating it with beta particles. The beta particles are emitted from a standard beta source, in our case Strontium/Yttrium 90 (^{90}Sr/Y). The material whose thickness is to be determined is put between the radioactive source and Geiger–Muller (G–M) detector. After measuring the mean background counts, the intensity of beta particles is measured first without the sample (I_0) and then by putting the sample on beta particles' way to the detector (I). The relation between I and I_0 is given by

$$I(x) = I_0 e^{-\mu x}, \tag{1}$$

where $I(x)$ and I_0 are the transmitted and the initial intensities of the beam, respectively. The parameter x is the sample thickness and μ is the absorption coefficient of the material. Fig. 1 shows the mechanical deformation of the sample under the effect of an applied force, where length and thickness of the sample depends on the applied force. It is clear that applied force depends on the time, and therefore, length and thickness of the sample depends on the time. Here we assume that the beam intensity varies with distance inside the sample medium, which is in turn dependent on time so we can rewrite Eq. (1) for time dependent I as

$$I(t) = I_0 e^{-\mu x(t)} \tag{2}$$

Although two different beta energies of 546.2 and 2282 KeV are present in the ^{90}Sr/Y decay, the combination of the statistical range distribution for beta particle and the continuous energy spectrum leads to the low exponential absorption (Eq. (2)). The absorption coefficient in this case is related to the maximum energy of $E_{max}=2.282$ MeV, according to the empirical rule (Varma, 2001):

$$\mu_{exp}\left[\frac{cm^2}{g}\right] = 17\left(\frac{1}{E_{max}\sqrt{(MeV)}}\right)^{1.14}. \tag{3}$$

Therefore a semi-empirical value of the absorption coefficient, μ_{exp}, has been used for beta particle attenuation within the sample material. The total number of beta particles passing through the sample during the period of experiment will be given by

$$N(t) = \int_0^t I(t)dt, \tag{4}$$

where $N(t)$ is the total number of β particles counted by G-M detector in the time interval between 0 and t. Using Eqs. (2) and (4)

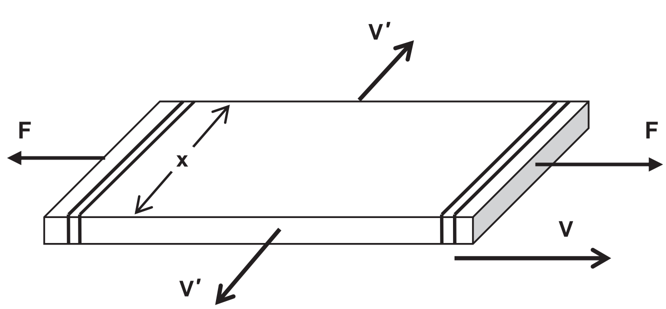

Fig. 1. Mechanical deformation of the sample under the effect of an applied force.

we get

$$N(t) = \int_0^t I_0 e^{-\mu x(t)} dt, \tag{5}$$

By considering that the sample length would change with a constant velocity V under a given applied force, its thickness x would also change with a different velocity V'.

Therefore in an arbitrary moment we get,

$$x = x_0 - V't, \tag{6}$$

where x_0 is the initial thickness of sample, on the other hand we assume that V and V' are related to each other by the following equation:

$$V' = \kappa V, \tag{7}$$

where κ is the proportionality coefficient. Substituting Eqs. (6) and (7) in Eq. (5) and integrating it over time can obtain,

$$N(t) = \frac{I_0 e^{-\mu x_0}}{\mu\kappa V}\left[e^{\mu\kappa V t} - 1\right]. \tag{8}$$

Eq. (8) shows the relation between the total number of transmitted beta particles with sample's initial thickness (x_0), absorption coefficient of the sample material (μ), strain velocity of sample (V), the coefficient (κ) and time (t).

As it is known, Poisson's ratio is defined as the ratio of the negative of the strain in the transverse direction to the strain in the longitudinal direction, this is

$$\nu = -\frac{\varepsilon_{transverse}}{\varepsilon_{longitudinal}} = -\frac{(\Delta l/l)}{(\Delta L/L)} = -\frac{(\Delta l/\Delta t)(\Delta t/l)}{(\Delta L/\Delta t)(\Delta t/L)} = -\frac{V'}{V}\frac{L}{l} = -\kappa\frac{L}{l}, \tag{9}$$

where L and $l=x_0$ are the initial length and thickness, of sample.

3. Experiment

The experiment was carried out on industrial rubber sample of $l=3$ mm$=x_0$ thickness, $L=90$ mm length, $w=51$ mm width and 0.94 g/cm^3 density, and also polyurethane sample of $l=4$ mm$=x_0$ thickness, $L=196$ mm length, $w=56$ mm width and 1.25 g/cm^3 density. To apply the strain to the sample, we used a Z wick Z100 special device shown in Fig. 2. The device has two jaws: one mobile and the other immobile. The sample is fixed in the device and goes under strain with a constant velocity of 10 mm/min. As mentioned above we used a ^{90}Sr/Y radioactive beta source with 5 μCi activity, and a Geiger-Muller tube as a detector for beta particles. The mean background count in the laboratory medium was 24 count/min. Fig. 3 shows the schematic configuration of the experiment.

In nearly all detector systems, there will be a minimum amount of time (the so-called "dead time") that must separate two events in order that they be recorded as two separate pulses. The observed counting rate was corrected for the loss counts due to the G-M counter dead time. If τ be the dead time of the system and g the observed counting rate, true counting rate, n, will be given by

$$n = \frac{g}{1 - g\tau} \tag{10}$$

For our G-M detector, the value of τ is 60 μs and it was measured with "two-source method" (Tsoulfanidis,1995). In this work the correction by the measured dead time affected the count rate.

When the rubber sample was under strain, the time was measured in each increment of 250 counts.