Polymer Testing 29 (2010) 358–368

Contents lists available at ScienceDirect

Polymer Testing

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

Test Method

Measurement of flexural modulus of polymeric foam with improved accuracy using moiré method

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ARTICLE INFO

Article history:
Received 6 October 2009
Accepted 29 December 2009

Keywords:
Flexural modulus
Polymeric foam
Moiré method

ABSTRACT

The flexural modulus of polymeric foams determined from three-point bending tests is usually inaccurate due to the local deformation undergone by the material during testing. The machine used in the test gives deflection values larger than the actual deflection of the foam specimen due to the deformation of the material at the loading point. This leads to errors in the computation of the modulus value. In this work, the deflection values of a beam made of polymeric foam in a three-point bending test were determined using the moiré method. The change in the moiré pattern at the neutral axis of the foam during loading was recorded and converted into deflection values. The deflection data were used to generate the stress–strain curve from which the flexural modulus of the foam material was determined. The proposed method was verified using aluminum beams, where a high correlation between the deflection data from the machine readings and the moiré method was obtained. The flexural modulus of the foam determined using the moiré method was found to be within 3% of the value published in the material data sheet.

1. Introduction

Polymeric foams derived from materials such as polyvinylchloride (PVC), polyurethane (PU), polyethylenterephtalate (PET), expanded polystyrene slabs (EPS), etc. are gaining important roles as the core material for sandwich structures in marine, aerospace, automobile, construction, insulation, packaging and several other applications [1–3]. This is attributed to their numerous desirable characteristics such as high strength-to-weight ratio, ability to absorb shock and impact loads, excellent thermal insulation and high buoyancy properties. Knowledge of the mechanical properties of the foam, described primarily by the modulus-of-elasticity (MOE) in bending (i.e. flexural modulus) determined from a three-point bending test, is necessary for the proper design and selection of the most suitable material for a desired application. However, accurate determination of the modulus of the foam material is difficult due to the deformation undergone by the material during the three-point bending test.

The mechanical properties of the foam materials depend on several factors, such as cell structure, foam density, method of manufacture and temperature. Extensive studies have been carried out in the past to understand the effect of these parameters on the material properties [e.g. [4–6]]. Tensile tests, compression tests and three-point or four-point bending tests have been conducted to obtain the mechanical properties, such as modulus of elasticity, hardness and strength [7–10]. Besides the traditional testing methods, simulation [11] and analytical methods [12] have been used to determine the effective MOE. Vajėlis and Vaitkus [10] showed the possibility of determining the MOE in bending using three-point and four-point bending tests for EPS. The modulus values obtained from both methods were compared and were found to differ when different test methods were used. The reason for the

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doi:10.1016/j.polymertesting.2009.12.011

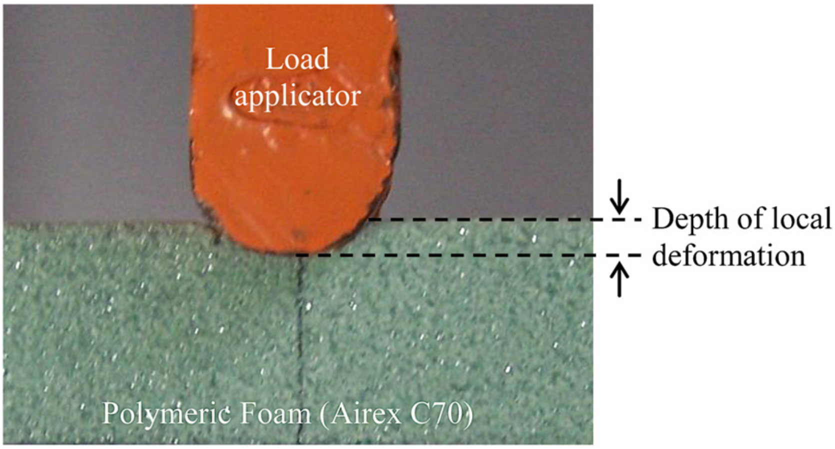

Fig. 1. Deformation of foam material due to load.

difference observed was not discussed in their paper, although this could be due to the different values of local deformation of the foam at the loading points.

The MOE of a specimen is determined from the straight line portion of the stress–strain curve obtained from a three-point bending test. However, the low stiffness of the foam and its porous nature cause local deformation at the contact point where the load is applied (Fig. 1). This produces error in the deflection values given by the machine and, therefore, leads to inaccurate values of MOE. The error can be reduced by attaching an intermediate skin, made of a higher stiffness material, placed between the foam and the load applicator. However, the additional layer can influence both the load and deflection values, thus producing an inaccurate MOE. To date, an effective solution to the local deformation problem in the three-point bending test on foams has not been proposed.

In an attempt to address the problem of local deformation of the polymeric foam during the three-point bending test, the moiré method is applied for measuring the deflection of a foam structure during the test. The deflection measured using this method is unaffected by the local deformation undergone by the foam when a load is applied, thus producing a more accurate MOE value of the material. The moiré method is a well-known strain measurement method [13] which has been used widely to study the strain rate and field of deformation on material surfaces [14,15].

The type of moiré effect known as geometric moiré was used in this study to determine the deflection of a polymeric foam beam specimen. Geometric moiré is an optical effect that is produced by the mechanical crossing of two gratings. A moiré pattern made up of linear fringes of lower frequency than the original gratings is created when there is an angle between the two overlapping gratings. When gratings of different pitch are used, the inclination of the fringes corresponds to the angle between the two gratings. In this work, the mechanism of formation of moiré fringe due to pure rotation was adopted to measure the deflection in the three-point bending test.

2. Theory

2.1. Deflection measurement using moiré fringes

Fig. 2(a) and (b) shows linear gratings of pitch p_1 and p_2 parallel to the x-axis, where $p_1 > p_2$. The gratings can be represented, respectively, by $y = mp_1$ and $y = np_2$ where $m = 1, 2, 3\ldots$ and $n = 1, 2, 3\ldots$ and are known as indicial numbers. When the two gratings are superimposed they overlap at points where $mp_1 = np_2$. If $p_2 = p_1 - \Delta p_1$ then at the overlapping points,

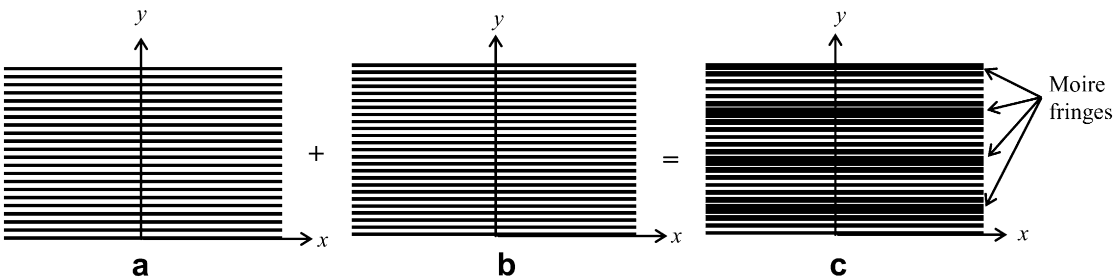

Fig. 2. Moire fringe formation from horizontal gratings.