The Specimen Optimization for the Equibiaxial Test of Elastomers

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Abstract: Elastomers have an important role in a many engineering applications today [1]. A need of exact description of their mechanical properties rises still more often. Therefore it is not enough to test these materials only in uniaxial tension test, but for complete characterization of them it is necessary to test elastomers in other deformation modes, as in equibiaxial tension and in pure shear [2]. These methods are not standardized. The optimization of the shape of specimen for the equibiaxial tension test is the object of this work. The bubble inflation technique [3] is used for the equibiaxial loading of the specimen of elastomer. The flat specimen of the elastomer is inflated through the circular ring in this method [4]. The influence of the specimen thickness and the ring diameter on the test results was evaluated and the optimal specimen dimensions were chosen.

Key-Words: bubble inflation, elastomer, equibiaxial, hyperelasticity, rubber, specimen, tension

1 Introduction

The measuring of the engineering constants for nonlinear material models demands special testing of the material. For accurate evaluation of hyperelastic material constants [1] we need to test material in all deformation modes that can occur during simulation. Usually three basic deformation modes are tested: uniaxial tension, equibiaxial tension and pure shear.

The equibiaxial tension test is the object of this paper. There are not standards for the equibiaxial tension tests of rubber. Thus we have to develop own test method [4]. A bubble inflation technique was chosen for the equibiaxial characterization of rubber. The flat specimen of rubber is inflated to the shape of bubble in this method. To find optimal shape of the specimen for this test method is our goal.

2 Problem Formulation

2.1 Material

A common rubber compound for tire manufacturing was used [5]. All specimens were made from the same material. The specimens with three different thicknesses were prepared (**1** mm, **2** mm and **3** mm) and tested to find out the thickness influence on the results.

2.2 Testing Method

A uniform circular specimen of elastomer is clamped at the rim and it is inflated using compressed air to one side. The specimen is deformed to the shape of the bubble (Fig.1). The inflation of the specimen results in a biaxial stretching near the pole of the bubble and the planar tension near the rim.

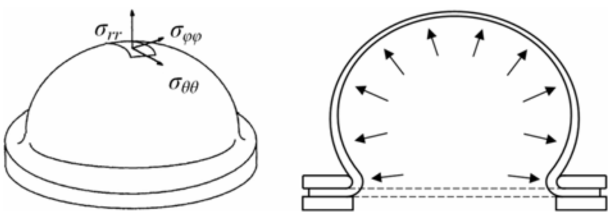

Fig. 1 The bubble inflation technique

The specimen inflation is recorded by digital camera. Stretch λ is generally the ratio between the current length l and the initial length l_0:

$$\lambda = \frac{l}{l_0} \tag{1}$$

With consideration of material incompressibility we can express the biaxial hoop stress $\sigma_{\theta\theta}$ on the pool of the inflated specimen as:

$$\sigma_{\theta\theta} = \frac{pr\lambda_{\theta\theta}^{2}}{2t_0} \quad (2)$$

Where p is the differential inflation pressure, r is curvature radius of specimen (on the pool of the bubble) and t_0 is the initial specimen thickness.

2.3 Comparing of Stress-Strain Curves

Due to the high nonlinearity we have to work with entire stress-strain curves (instead of only one numerical parameter). Thus we need special statistic methods to compare such results. The statistical hypothesis that polynomial regression curves of three groups of data (three thicknesses or three clamping ring diameters) are the same as regression curve for all data together is tested. The test criterion F is evaluated by the formula:

$$F = \frac{\dfrac{RSS_T - (RSS_1 + RSS_2 + RSS_3)}{8}}{\dfrac{(RSS_1 + RSS_2 + RSS_3)}{N-12}} \quad (3)$$

where: RSS_T is residual sum of squares of all data together, RSS_1, RSS_2 and RSS_3, are residual sums of squares of particular groups of data and N is number of observations in the group of all data.

2.4 Experiment

Schematic view of the testing equipment is presented in Fig. 2. The specimen (a) is fixed between two rings. The three different pairs of rings with different inner diameters (**40** mm, **45** mm and **50** mm) were used to find out importance of inner diameter dimension on the test. Rings are clamped in a support (b). Next function of the support is distribution of the compressed air to one side of the specimen. The air pressure is regulated with pressure regulator (c) and regulating valve (g). The current pressure value is recorded using a pressure sensor (d). The inflation of the specimen is recorded in small time intervals (1 s) using a digital camera (f). A computer (e) is used to control the pressure valve (g).

The white strips were drawn in the central area of specimen for stretch measurement. It is important to measure elongation and curvature radius only in the area near to pole (between the strips) of inflated specimen and not on entire bubble contour because the equibiaxial state of stress occurs only on the pole.

The material was loaded until failure. We obtained values of stretch ratios $\lambda_{\theta\theta}$ and curvature radii r from image analysis of taken pictures. The result of the test is stress-stretch dependence [6].

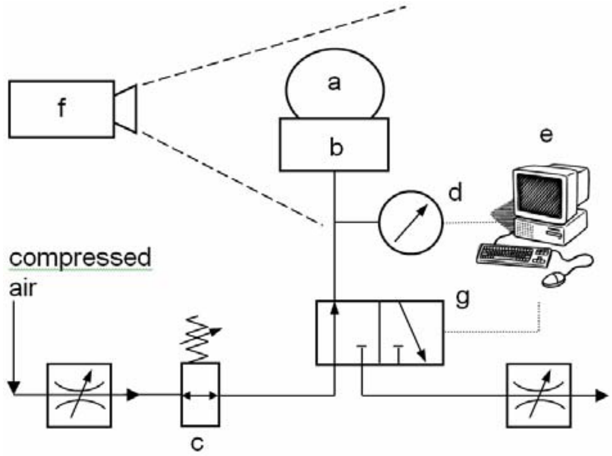

Fig. 2 Schematic view of the testing equipment

3 Problem Solution

Three different specimen thicknesses and three different clamping rings were used. All combinations were tested. It means that we have 9 different experiments and 9 sets of results.

At first all results were assorted according to inner diameters of clamping rings. Thus we got three groups of result for three diameters (40 mm, 45 mm and 50 mm) – 50 mm diameter is shown in Fig. 3. In each group all three thicknesses of specimen are included.

Then the same results of all 9 experiments were assorted according to specimen thickness. Now we have got three groups for three thicknesses (1 mm, 2 mm and 3 mm) – 1 mm thickness is shown in Fig. 4. In each group all three inner diameters of clamping rings are included.

Statistical evaluations of coincidence of data inside these six groups were performed. The influence of specimen thickness was examined in the groups for different inner diameters of clamping rings (Table 1). And the influence of inner diameter of clamping rings was examined in the groups for different specimen thicknesses (Table 2). Test criteria F were computed from formula (3) and used for data evaluation. If value of criterion F is high we can not accept hypothesis about coincidence of regression curves.

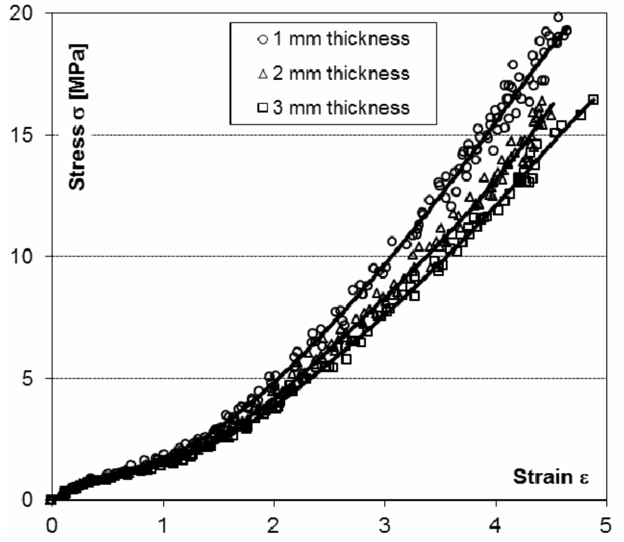

Fig. 3 Stress-strain diagrams for specimens of all three thicknesses clamped in the ring of 50 mm inner diameter

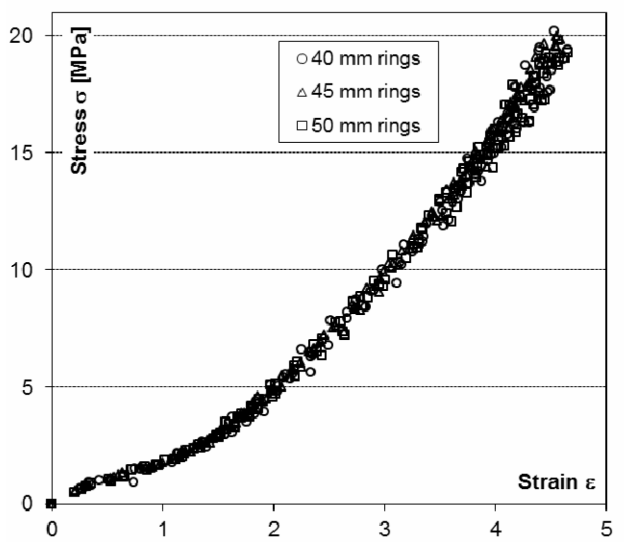

Fig. 4 Stress-strain diagrams for specimens with 1mm thicknesses clamped in all three rings

4 Conclusion

Differences between the specimens with different thicknesses are shown in Fig. 3. We can recognise separated data for each thickness, particularly with the strain above 1,5. All data in Fig. 3 are from the test with 50 mm clamping rings. The very similar situation occurs if we use next two pairs of clamping rings (40 mm and 45 mm).

There are data only for one thickness (1 mm) but using all three diameters of clamping rings in Fig. 4. We can see that data are very close together and data of different clamping rings visually coincide. Again very similar situation occurs for next two thicknesses (2 mm and 3 mm).

We can see from Table 1 and 2 that the thickness influences the results much more than the ring diameter. And this fact is confirmed in the Fig. 3 and 4.

Results assorted according to the inner diameter of clamping ring [mm]	F
40	201,21
45	338,59
50 (Fig. 3)	479,30

Table 1 Influence of thickness on the test results

Results assorted according to the specimen thickness [mm]	F
1 (Fig. 4)	6,02
2	5,16
3	21,05

Table 1 Influence of inner diameter of the clamping ring on the test results

According to the statistic tests even the data in Fig. 4 are not coinciding but we can see that they are very close together and we can say that influence of inner diameter of clamping rings is minimal and not significant for this test. On the other hand the specimen thickness influences results much more and this is clear form Fig. 3 and also from statistic tests (Table 1 nad 2).

The next factor is the thin shell assumption used in formula (2). It means that the ratio between the thickness of the inflated membrane and the curvature radius has to be small enough. From this point of view we can expect the smallest thickness (1 mm) in combination with the largest diameter (50 mm) as the most appropriate for the test.

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