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MODELING OF HYSTERETIC EFFECTS IN INDENTATION TEST OF ELASTOMERIC MATERIAL[1]

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Abstract

The aim of this work is to identify the parameters of model of elastomeric material which satisfactorily describes hysteretic looses in loading-unloading cycle of micro-indentation. The problem is solved by direct 3D computer simulation method. Reasonable choice of material model, friction law and their parameters defines the quality of computer simulation. To provide the results, the full scale experiments are compared with the computer simulation tests to verify the material model. Two kinds of experimental tests are made. The first test is compression of the thick ring of elastomeric material by flat punch with constant velocity of strain. The programs of the tests are loading - unloading cycle and loading - relaxation of the stress. The second test, was used, is indentation of elastomeric material by spherical indenter using the same rate of strain velocity loading and unloading cycle. The parameters of Prony series are obtained according to verification experiment result.

Key words: Computer simulation test; Hysteretic looses; Indentation; Elastomeric material.

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1 INTRODUCTION

Contact problems of viscoelastic materials are urgent now in many mechanical applications. It is necessary to know not only the value of contact stresses but their distribution as well. So as viscoelastic materials have a time-dependent response, the contact aria and contact stress distribution are also time dependent. Since contact of deformable solids is a nonlinear problem, the contact problem of viscoelastic bodies is rather complicated, nonlinear and time-dependent one. To model friction in sliding of rough surface over viscoelastic body it is required to analyze subtle effects, related to low loads and displacements but in the same time related to sufficient deformation in loading-unloading cycle. Some of these effects associated with material properties can be obtained from study of an indentation process.

Results in study of liding contact of viscoelastic solids are achieved by analytical modeling.[1,2] But a definition of material model parameters is a very knotty question. As a rule, viscoelastic materials possess a spectrum of relaxation times. They have different effective modulus for different frequency of interaction. So the first step on the way to sliding contact is to determine properties of viscoelastic material - the model of material and its parameters. This can be done using the macro- indentation full scale and computer simulation verification experiments. Now indentation is an effective technique to measure mechanical properties in different scales.

Generally, the stress function of a viscoelastic material is given in an integral form and the kernel functions are represented in terms of Prony series in calculations. The objective of this work is to develop a method to obtain a minimum quality of Prony components for given deformation velocities and load amplitudes.

2 PROBLEM FORMULATION

The direct 3D computer modeling method is used. The problem is considered in 3D formulation (not in axisimmetric one) in order to use this finite elements (FE) model for description of indentation process with sliding. A contact scheme is shown on the Figure 1. This finite element model is a virtual analog of full scale test. The size of elements is chosen with respect to accuracy of received stress, strain and displacements fields in contact zone and computational costs. A thick ring of elastomeric material is fixed on its down butt, and the rigid spherical indenter is in contact with the upper butt of the ring. Outer diameter of the ring, its inner diameter and height are 53,6 mm, 40,2 mm and 7 mm respectively, radius of indenter is 0,8 mm.
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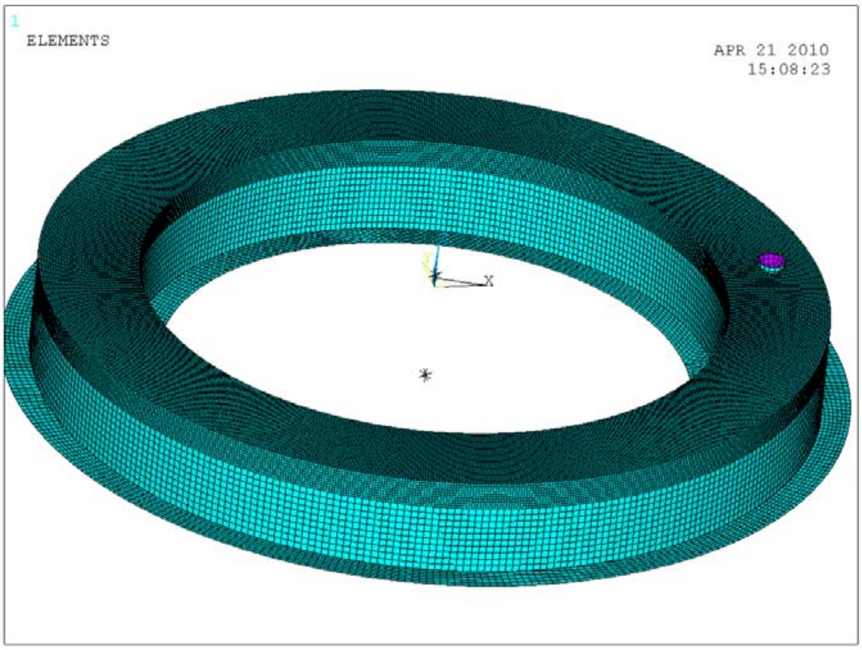

Figure 1. Finite element model of micro-indentation test. Contact scheme.

The material is assumed incompressible. Within the context of small strain theory, the constitutive equation for an isotropic viscoelastic material can be written as:

$$\sigma = \int_0^t 2G(t-\tau)\frac{d\varepsilon}{d\tau}d\tau + I\int_0^t K(t-\tau)\frac{d\Delta}{d\tau}d\tau$$

where:
σ = Cauchy stress
ε = deviatoric part of the strain
Δ = volumetric part of the strain
G(t) = shear relaxation kernel function
K(t) = bulk relaxation kernel function
t = current time
τ = past time
I = unit tensor
The kernel functions are represented in terms of Prony series, which assumes that:

$$G = G_\infty + \sum_{i=1}^{n_G} G_i \exp\left(-\frac{t}{\tau_i^G}\right)$$

$$K = K_\infty + \sum_{i=1}^{n_K} K_i \exp\left(-\frac{t}{\tau_i^K}\right)$$

where:
G_∞, G_i = shear elastic modules
K_∞ , K_i = bulk elastic modules
τ^G, τ^K = relaxation times for each Prony component
The integral function can recover the elastic behavior at the limits of very slow and very fast load.

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Coulomb friction law with friction coefficient μ=0,001 is used (full scale micro-indentation tests shows that results correlate weakly with the friction coefficient value, it is obtained by using different lubricants in the tests).

The experiment program is consisted of 5 steps. The indenter tip does not contact with specimen. Than it moves to the ring surface with velocity V=0.002 mm/s until a preset load achieves 10 mN and stay in this position 10 seconds. This configuration is assumed as initial (zero by load and penetration). The indenter moves in vertical direction with chosen velocity till penetration of the indenter tip become 100 μm. Diapason of indenter mouton velocities is from 1 μm per second to 100 μm per second (quasi-static problem). Then the indenter moves in opposite direction unloading the specimen. Switch time between loading and unloading branches is approximately 5 sec. As result we obtain hysteretic loop of loading-unloading cycle.

2.1. Verification of the Material Model Parameters

Another test, which consists of three stages, is used for verification of the material model parameters. A first stage is a compression of the thick viscoelastic ring between two flat punches with constant velocity of holder's motion. A full range of strain velocities is 0,1-10 sec^{-1}. A lubricant is used to avoid significant inhomogeneous stress and strain distributions. The holders are fixed on the next stage (relaxation) for some time (approx. 300 sec.). The last stage of the test is full unloading of specimen.

Elastic properties of material are received from the compression stage, viscoelastic model parameters are obtained from the relaxation curve using least-squares method. Quality of material modeling is tested by comparing of full scale and virtual tests results. Verification computer simulation test, which completely repeat all the conditions of the full scale experiment, must provide satisfactory choice of material model parameters.

FE model of verification test is shown on Figure 2.

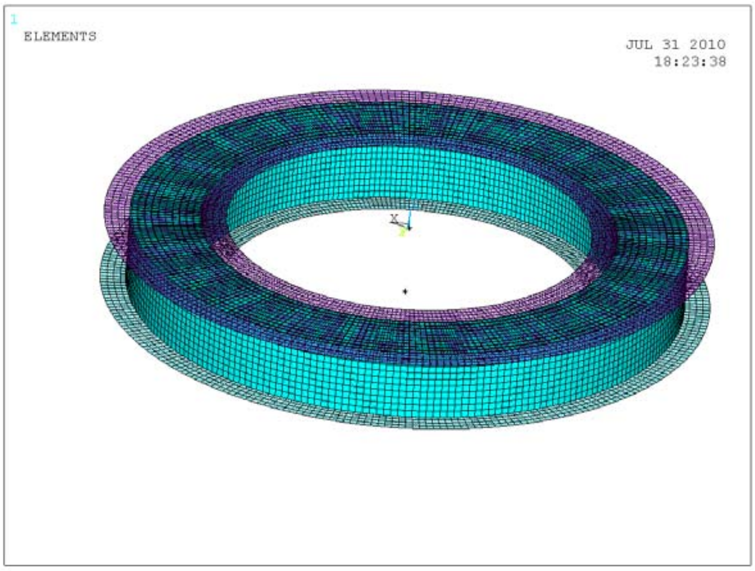

Figure 2. Finite element model of verification test.

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3 RESULTS AND DISCUSSION

3.1. Material Model Parameters

The following parameters of viscoelastic elastomer model - Young's module (E=8 MPa), Poisson ratio (v=0,49); Prony coefficients ($K_0=K_\infty$=133MPa, G_1=2,21 MPa, G_2=0,278 MPa; G_∞=0,2 MPa, $\tau_1^G=\infty$, τ_2^G =10 sec) - give good agreement between full scale and virtual tests (Figure 3).

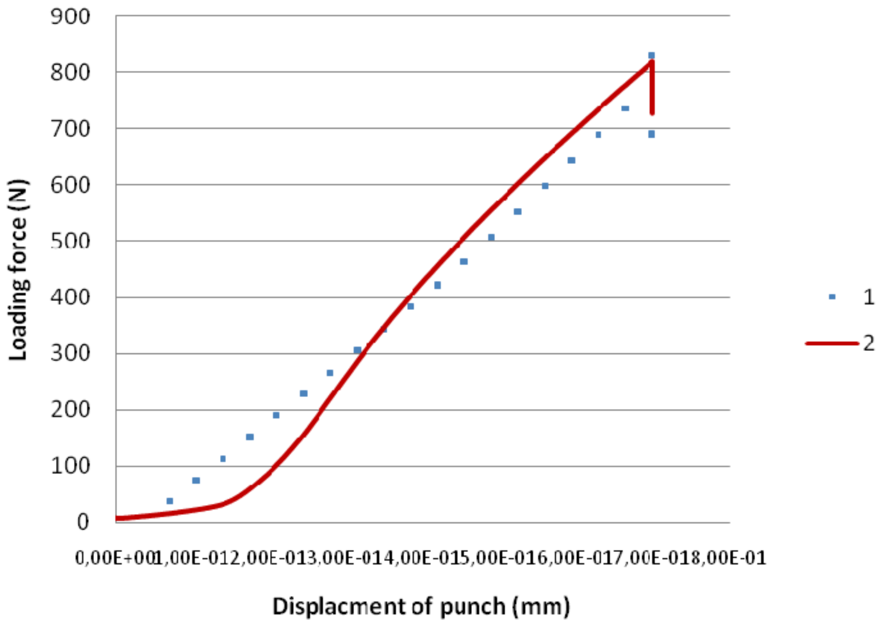

Figure 3. Loading force via punch displacement. 1-calculation; 2-experiment

3.2 Results of Indentation tests

The presented computational model is used for analysis of subtle effect - hysteretic loop in indentation cycle. The results of full scale and virtual indentation tests are shown on Figure 4. One can observe good accordance between them with the exception of limited region near switch time from loading and unloading branches.

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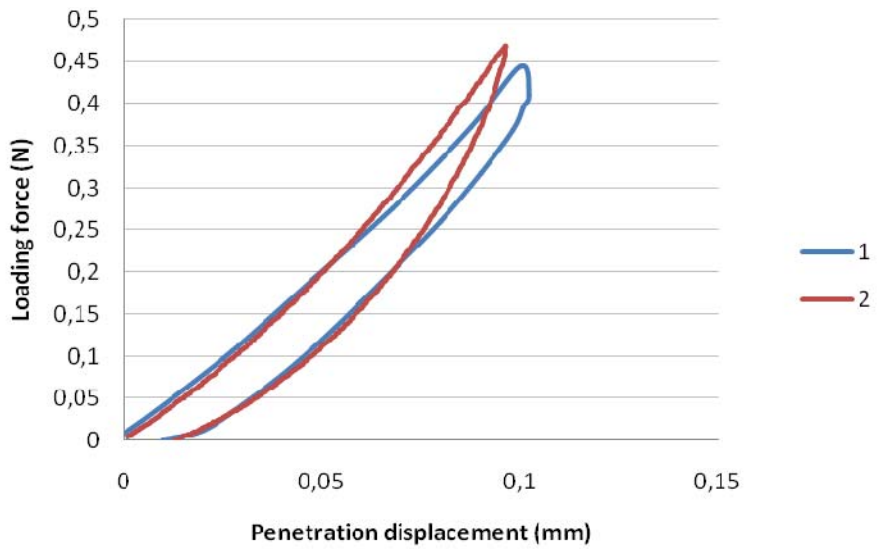

Figure 4. Hysteresis loop in indentation test, velocity of indenter tip penetration V=0,01mm, depth of penetration 100 mkm .

4 CONCLUSIONS

In this work parameters of viscoelastic elastomer constitutive equation are identified and 3D computational model for micro-indentation process is verified. The identification and verification procedures are based on comparison of full scale and virtual tests. The results of both experiments give appropriate accordant.

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