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NUMERICAL INVESTIGATION OF THE RELATION OF SHORE A HARDNESS AND HYPERELASTIC PARAMETERS FOR DIFFERENT TYPES OF RUBBERS

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1. Introduction

The standardized Shore A hardness test [1] is one of the most commonly used measurement for the quality check of rubber-like materials [2,3]. The Shore A hardness test provides a quick, simple and non-destructive measurement method for the evaluation of the elastic properties of rubber specimens [4]. However, due to the highly nonlinear material behaviour of rubber and the complexity of indentation process itself, an accurate and direct relationship between the elastic properties and the Shore A hardness is hard to determine.

Several studies investigated the relation of Shore A hardness and the elastic modulus. Gent's relation gives and empirical formula between the ASTM-2240 Shore A hardness (S) and the initial Young's modulus as [5]

$$E = 0.7134\frac{56 + 7.66S}{254 - 2.54S}. \qquad (1)$$

In the study of Qi et al. another empirical formula was provided based on FE-simulation of the indentation [4]. This defines the relationship for $20 < S < 80$ as

$$\log_{10} E = 0.0235S - 0.6403. \qquad (2)$$

However, no publication was found which examines the effect of non-linear stress-strain relations on the Shore A hardness and elastic measures like the 100% and 300% moduli.

The research project COMPOMER aims to develop a methodology of high-fidelity material parameter fitting tailored for rubber-like materials characterized by hyperelastic constitutive models. The concept includes an automatic pre-processing of available mechanical test information like the Shore A hardness as well as uniaxial tensile and compressive experiments to select theoretically the best model.

In this contribution, the effect of the nonlinear hyperelastic constitutive models is investigated using various FE simulations and rubber types on the Shore A indentation process. Several experimentally fitted hyperelastic potentials were investigated and the effect of the model parameters are compared with the simulated and measured Shore A hardness values. Experimental work was carried out on different natural rubber raw materials to provide experimental validation for the simulation results.

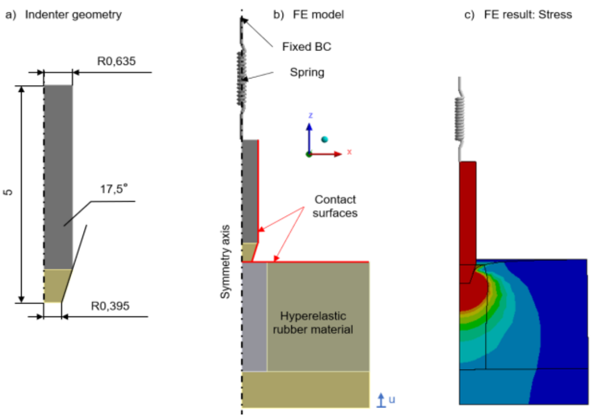

Fig. 1. The applied a) indenter geometry and b) axisymmetric FE model and c) the obtained stress distribution

2. Finite element simulations

Quasistatic FE analysis was performed in Ansys [7] to model the Shore A indentation process. A quarter-model was applied, where the indenter was meshed with linear hexa-elements; for rubber specimen linear tetra-elements were applied. The contact between the indenter and the specimen was modelled with frictionless contact properties. The indenter was contacted to a linear grounded spring with a calibrated stiffness value from existing hardness measurement data. For the bottom surface of the rubber specimen $u = 2.5$ mm displacement was prescribed accordingly to the ASTM standard [1] (see Fig. 1).

The indenter was modelled as linear elastic material (i.e. Hooke's law), while for the rubber several incompressible hyperelastic potentials (W) were adopted. In the numerical analysis an extended parametric study was carried out and the correlation between the model parameters were derived using statistical approaches. The theoretical relationships derived from this parametric study were validated with several experimental Shore A measurement data.

3. Experimental validation

For the validation of the simulation results a detailed experimental study was carried out using natural rubber (NR) specimens. Several different NR specimens were created with different chemical compositions using different concentrations (0-47%) of carbon blacks (N330 and N772). After that the uniaxial engineering stress – stretch ($P - \lambda$) curves were measured for using both compression and tension specimens and the Shore A hardness values were also measured for each specimen (see Fig. 2). Several hyperelastic models were fitted to the uniaxial test data and the Shore A tests were simulated. As next, the measured and simulated Shore A values were then compared and calibrated.

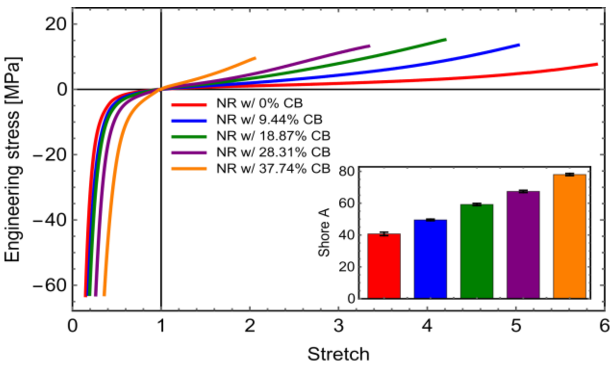

Fig. 2. The measured engineering stress-strain curve for NR specimens with different chemical compositions

4. Results

The comparison of the theoretical and the experimental results shows that the two empirical formulae cannot predict the Shore A – elastic modulus relation accurately (see Fig. 3). Furthermore, the parameters obtained from the nonlinear behaviour of the fitted strain energy potential show also correlation with Shore A hardness.

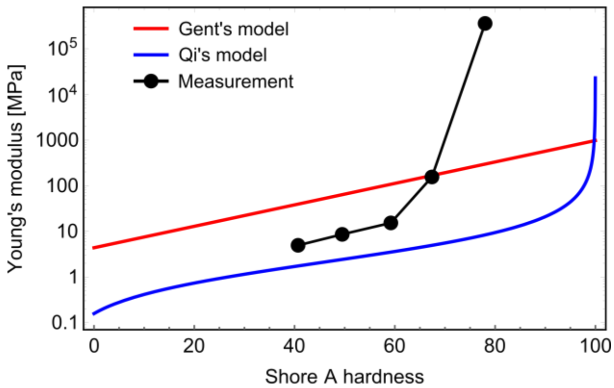

Fig. 3. The measured relation of the Young's modulus and Shore A hardness and the theoretical model predictions

Acknowledgments

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