XVI Konferencja Naukowo-Techniczna
TKI2022
TECHNIKI KOMPUTEROWE W INŻYNIERII
18–21 października 2022

Constitutive Law Identification of PUR Components Using Hybrid Experimental-Numerical Approach

Krzysztof Junik, Szymon Duda, Kayode Olaleye, Paweł Zielonka, Grzegorz Lesiuk, Krzysztof Jamroziak

Department of Mechanics, Materials and Biomedical Engineering, Wroclaw University of Science and Technology
email: krzysztof.junik@pwr.edu.pl, grzegorz.lesiuk@pwr.edu.pl, szymon.duda@pwr.edu.pl, kayode.olaleye@pwr.edu.pl
pawel.zielonka@pwr.edu.pl, krzysztof.jamroziak@pwr.edu.pl

ABSTRACT: This paper presents an approach that involves a computational method to evaluate various hyperelastic material models for polyurethane of 80 and 90 ShA. The finite Element Method is being applied to deliver strain – displacement curve and model parameters. Several material models were assessed such as reduced polynomial, Arruda – Boyce, and Ogden. The experimental data from uniaxial and planar tests were uploaded to determine model parameters. Evaluation exhibits that Ogden 3 – parametric fits the experiment data the most accurately. The numerical model shows acceptable conformity with provided experiment data. A numerical model is represented by a solid geometry of a quarter of the diabolo-shaped specimen. Finite Element Analysis was performed using Abaqus software in a static term.

KEYWORDS: crack growth, fatigue, FEM, lifetime prediction, polyurethane

1. Introduction

Tires, seals, bushings, boots, and other items are only a few examples of the many applications for polymeric materials like rubber and polyurethanes. Rubber and thermoplastic polyurethane materials share comparable properties in that they are both elastic and flexible. Thermoplastic polyurethanes, however, are frequently preferred over rubber due to their rubber-like properties and strong resilience to fatigue under repeated stress loadings. However, fatigue life analysis, including lifetime prediction of solid thermoplastic polyurethane under cyclic loading conditions, is either theoretically or experimentally detailed in several articles on the material behavior of rubber. For example, see [1-4]. The relationship between the morphology and the mechanical stress-strain behavior has been the focus of research on solid thermoplastic polyurethane materials up until this point [5, 6]. Refer to [7] for a thorough explanation of mechanical modeling of solid polymers.

The research aims to compare the effect of PUR 80 ShA and 90 ShA hardness on selected mechanical properties – in particular, the propensity to cracking and fatigue – and to evaluate rheological changes expressed in terms of the material's tendency to stress relaxation.

The aim of the study is to find an appropriate numerical model describing the behavior of an elastomeric material based on its experimental characteristics.

2. Materials and Methods

An approach is presented that involves a computational method to evaluate various hyperelastic material models for polyurethane of 80 and 90 ShA. The finite Element Method is being applied to deliver strain – displacement curve and model parameters. Several material models were assessed such as reduced polynomial, Arruda – Boyce, and Ogden. The experimental data from uniaxial and planar tests were uploaded to determine model parameters. Evaluation exhibits that Ogden 3 – parametric fits the experiment data the most accurately. The numerical model shows acceptable conformity with provided experiment data. A numerical model is represented by a solid geometry of a quarter of the diabolo-shaped specimen. Finite Element Analysis (FEA) was performed using Abaqus software in a static term.

Boundary conditions need to be applied to the geometry to provide adequate loading conditions. To keep the symmetry of the specimen, the boundaries along the x and z-axis were provided. Transfer of the load to the sample is pursued by coupling the reference points to the inner surfaces (Fig. 1).

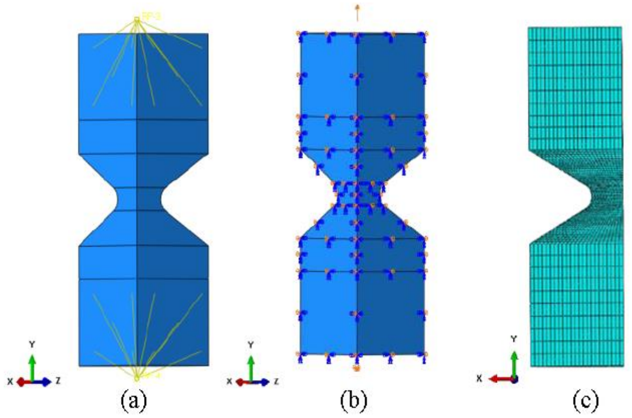

Fig. 1. Representation of boundary conditions applied to the specimen and meshed object, (a) coupling connection, (b) symmetry boundary conditions, (c) meshed object used in numerical simulation

Presented geometry with the applied loading conditions meshed into a finite continuum object. The mesh applied to the object consists of 39 402 quadratic hexahedral elements of type C3D20RH. The element size set for this model is 2 mm, however, some regions were enriched with additional nodes (Fig. 1c). The simulation was run to reflect the static tensile test of this diabolo-shaped specimen and provide strain value concerning the displacement.

3. Simulation results and discussion

Two sets of experimental data (PUR 80 ShA and PUR 90 ShA) were provided to choose the best fitted hyperelastic material model. The uniaxial and planar test data allow choosing the more accurate model. Having the experimental data, the evaluation was performed for uniaxial and planar tests for models such as reduced polynomial, Ogden, and Arruda-Boyce. The evaluation for the uniaxial test was pursued up to the strain of 7.0 mm/mm according to Fig. 2 and to the strain of 3.0 mm/mm according to Fig. 3. Ogden model is described below:

$$W = \sum_{i=1}^{N} \frac{2\mu_1}{\alpha_i^2}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) \qquad (1)$$

where: μ_i and α_i material constants.

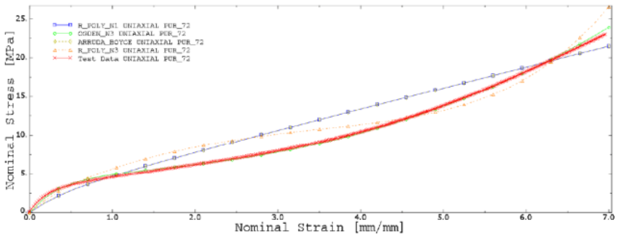

Fig. 2. PUR 80 ShA stress-strain relationship for uniaxial test for experimental data and various material models

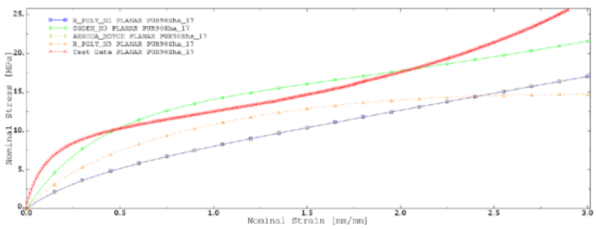

Fig. 3. PUR 90 ShA stress-strain relationship for planar test for experimental data and various material models.

Presents the curves for each model and parameter model shown in Tab. 1.

Table 1. Ogden model parameters

Constants	Material	Series (N) 1	2	3
μ_i	PUR 80ShA	4.34400372	0.210081339	4.921467147× 10^{-3}
	PUR 90ShA	-707.693690	316.165559	401.397194
α_i	PUR 80ShA	-0.380731347	3.47276528	-6.93803394
	PUR 90ShA	1.13390568	1.34789067	0.904727974

For the PUR 90 ShA material, the fourth value of the constants was determined, where μ_i estimated 8.765965905×10^{-3} and α_i is -7.00870716.

The next step exhibits the accuracy of the numerical results with FEA (Fig. 4).

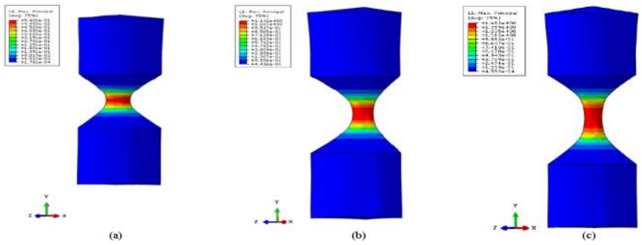

Fig. 4. Strain values for displacements: (a) 1-5 mm, (b) 2-10 mm, and (c) 3-15 mm

Only an overestimation is noticed for PUR 90ShA between the displacement of 3 thru 15 mm. This might be caused by the not accuracy of the fitted parameters in terms of the planar experimental data, where the model's curve cannot fit the experimental data (Fig. 5b).

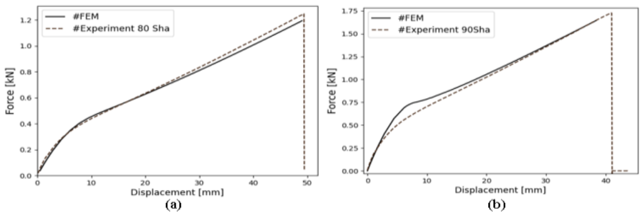

Fig. 5. Comparison of the results obtained from numerical simulation and experiment: (a) PUR 80 ShA, (b) PUR 90 ShA

4. Conclusion

Provided outcomes showed that the Ogden material model with 3 material parameters predicts accuratly the behavior of PUR material with 80 ShA hardness. The Ogden material model with 4 material parameters predicts acceptably the behavior of PUR material with 90 ShA hardness. To sum up, the behaviour of the two polyurethane materials with different hardnesses can be successfully described by Ogden's constitutive model.

References

[1] Carleo F., Barbieri E., Whear R., Busfield J.J.C., Limitations of viscoelastic constitutive models for carbon-black reinforced rubber in medium dynamic strains and medium strain rates, Polymers, Vol. 10, No. 988, 2018, https://doi.org/10.3390/polym10090988.

[2] Guo Q., Zaïria F., Guo X., *A thermo-viscoelastic-damage constitutive model for cyclically loaded rubbers. Part I: model formulation and numerical examples*, Int. J. Plast. Vol. 101, pp.106-124, 2018.

[3] Liu M., Hoo Fatt M.S, *A constitutive equation for filled rubber under cyclic loading*, Int. J. Non-Lin. Mech., Vol. 46, No. 2, pp. 446-456. 2011.

[4] Vaikuntam S.R., Bhagavatheswaran E.S., Xiang F., Wießner S., Heinrich G., Das A., Stöckelhuber K.W., *Friction, abrasion and crack growth behavior of in-situ and ex-situ silica filled rubber composites*, Materials, Vol. 13, 2020, https://doi.org/10.3390/ma13020270.

[5] Eberlein R., Pasieka L., Rizos D., *Validation of advanced constitutive models for accurate FE modeling of TPU*, Adv. Mater. Lett., Vol. 10, No. 12, pp. 893-898, 2019.

[6] Qi H.J, Boyce M.C., *Stress-strain behavior of thermoplastic polyurethanes*, Mech. Mater., Vol. 37, No. 8, pp. 817-839, 2005.

[7] Bergstrom J.S., *Mechanics of solid polymers*, Elsevier, London 2015.