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Mechanical Behavior and Stiffness of a Polyurethane Bushing of a Passenger Car Suspension

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Abstract. **Suspension bushings play an important role in reducing vibrations, minimizing noise, absorbing road irregularities, and controlling joint movements. Polyurethane bushings, in particular, contribute to improved vehicle handling, exhibiting lower moments of inertia and greater strength under increased loads. However, this enhancement in performance may come at the expense of reduced ride comfort. This paper presents the results of a study on the mechanical characteristics of polyurethane material and the stiffness of bushings made from the same material, specifically in the context of the MacPherson front independent suspension. To achieve this, mechanical tension tests were conducted on polyurethane specimens, obtaining stress-strain curves. Additionally, a three-dimensional geometric model of the polyurethane bushing was created using the SolidWorks software. The paper presents the results of bushing stiffness obtained through nonlinear Finite Element Analysis (FEA). Experimental determination of radial stiffness was also performed, and the results were compared for validation.**

Keywords: experimental, FEA, polyurethane bushing, stiffness, suspension.

I. Introduction

The bushings play a critical role in the suspension system, serving to diminish the magnitude of vibrations and noise while also influencing the handling characteristics of the vehicle.

The rubber bushings of car suspensions are the subject of many studies by using FEA with modern software products [1]-[3], by further developing known analytical dependencies [2], [4], [5] and by experimental studies [1], [5], [6].

Various researchers [1], [5], [7]-[11] have addressed issues concerning the mechanical properties, analysis, and validation of various FEA models of elastomers. Their investigations delve into understanding the behavior of elastomers when subjected to diverse influencing factors.

Polyurethane bushings possess the strength and resilience of wood and plastic, combined with the flexibility and elasticity of rubber. Their durability makes them particularly suitable for automotive use. As suspension bushings are continuously subjected to stress and stretching, the hardness of polyurethane provides drivers with enhanced road feel and increased vehicle control [12].

The primary advantage of polyurethane over rubber as a bushing material lies in its durability. Polyurethane's strength and toughness enable it to outlast rubber by five to ten times [12], making it a preferred choice for longer life cycles.

In a study by [13], polyurethane bushings for suspension arms were designed using rapid prototyping and simulated with SolidWorks. Other research [14], [15] focused on fatigue and stress analysis of anti-roll bars using FEA with various polyurethane rubbers. Additionally, [16] presented four types of mechanical tests (tear, tension, compression, abrasive wear) on polyurethane materials with different hardness levels (80 and 90 ShA) used in car suspension systems, elucidating the impact of hardness on key mechanical properties.

The study aims to determine the mechanical characteristics and stiffness of polyurethane bushings. To achieve this objective, mechanical tension tests were conducted on polyurethane specimens to obtain stress-strain curves. Subsequently, a three-dimensional geometric model of the polyurethane bushing was generated using SolidWorks software. The determination of bushing stiffness was carried out through nonlinear FEA, and the obtained results were compared with experimental data.

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II. Materials and Methods

The study focuses on analyzing a polyurethane bushing used in the suspension arm of a passenger car. These bushings serve as elastic supports for the arm, requiring the determination of stiffness to ensure accurate fixation. Fig. 1 depicts a 3D model of the polyurethane bushing without the outer sleeve.

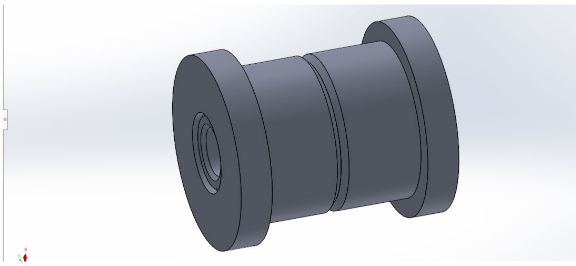


Fig. 1. 3D model of polyurethane bushing.

The stiffness of the polyurethane bushing was assessed through non-linear SolidWorks Simulation analysis. Elastic properties of the polyurethane were approximated using the Mooney-Rivlin material model. Material constants were derived from experimental results of stress-strain curves obtained from uniaxial tension tests on specimens. A Poisson's ratio close to 0.5 was chosen [1], and the density was calculated as 1110 kg/m^3.

The hardness of the specimen and the polyurethane bushing were determined by using a tester Shore A Durometer. This device is commonly utilized for measuring the hardness of various materials, including general rubber, synthetic rubber, soft rubber, poly-resin, wax, and others, across a range of hardness levels, from low to high. The characteristics of the tester Shore A Durometer are pressure force 0.55 N – 8.06 N, range 0 – 100 Shore A and accuracy ±2. Fig. 2 show Hardness tester Shore A Durometer, polyurethane bushing and specimen.

Fig. 2. Tester Shore A Durometer, specimen and bushing.

Inner sleeve of the bushing is made of aluminum alloy 2024, according to DIN 3.1355 while outer sleeve is made of steel-normalized 4340, according to EN 10250. Mechanical properties of metal parts of the polyurethane bushing are shown in Table 1.

Table 1 Mechanical properties.

Properties	Aluminum	Steel
Elastic modulus, MPa	73000	205000
Poisson's ratio	0.33	0.32
Mass density, kg/m^3	2800	7850

A three-dimensional tetrahedral curvilinear mesh was generated (Fig. 3). It includes 108 619 nodes and 589 840 elements.

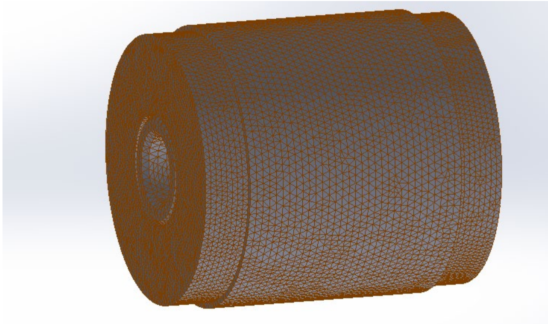


Fig. 3. FEA mesh.

The main goal of the experimental tests were to determine the curves "stress-strain" and "force-displacement". Tests was performed at Electric universal testing machine „WDW-20A". Fig. 4 shows the machine was used. The maximum load of the machine is 20 kN. Both parts of the machine were used for conducting the experiments. The stress-strain curve of the specimen was generated using the dedicated section of the machine designed for tensile testing (1). Similarly, the force-displacement curve of the polyurethane bushing was acquired using the compression testing section (2). Additional components have been developed specifically for conducting the polyurethane bushing compression test. Data from the experimental studies were recorded and exported to an Excel file. Each test was conducted thrice for accuracy and reliability.

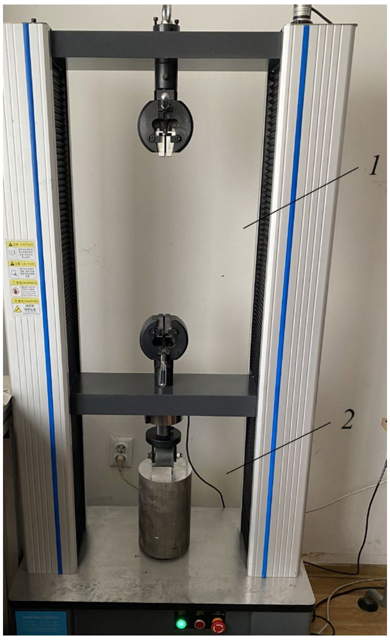


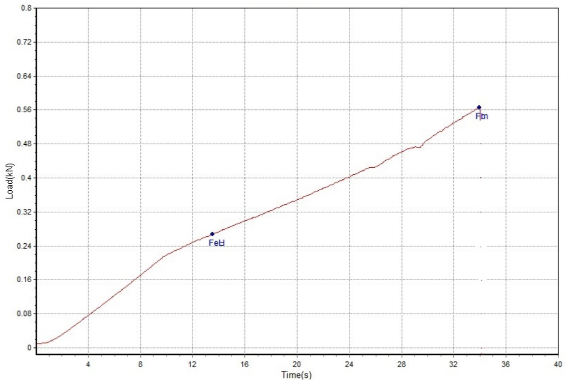
Fig. 4. Experimental test machine.

III. Results and Discussion

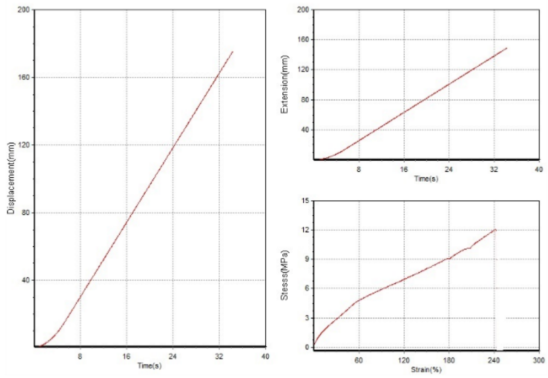
The measured hardness of the polyurethane bushing and the specimen is 80 Shore A.

Pre-tensioning of the specimen was done to eliminate the Mullin's effect.

Fig. 5 presents the result of the software screen for one of the tensile tests performed for the specimen.



a) Load – time curve

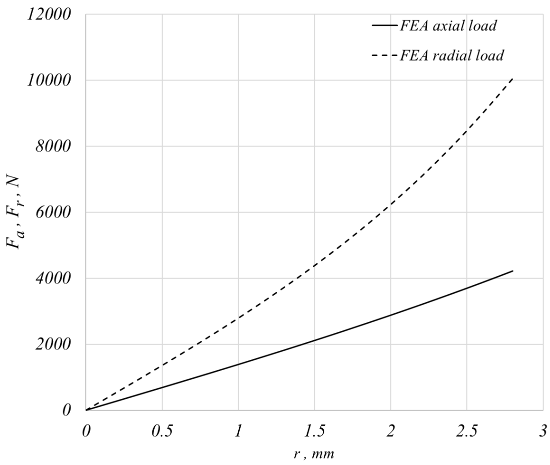


b) displacement, extension and stress representation

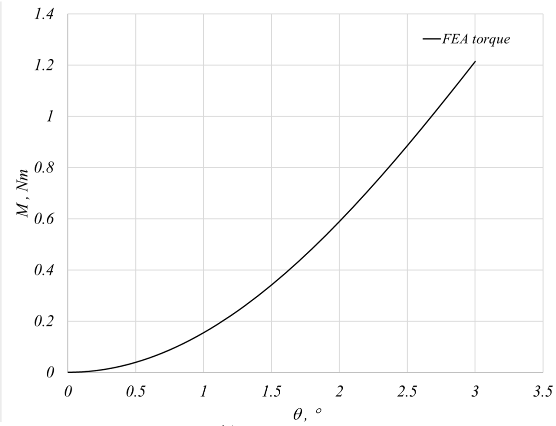
Fig. 5. Experimental results of tensile test.

The experimental stress-strain curve, as depicted in Fig. 5b, served as the basis for determining the necessary parameters for FEA simulation. The five constants of the hyperelastic Mooney-Rivlin model were determined by curve fitting and a non-linear analysis was performed.

Fig. 6a illustrates the results obtained through FEA depicting the variation of loads as a function of the displacement of the polyurethane bushing. Additionally, Fig. 6b presents the FEA results showing the torque variation as a function of rotation.



a) axial and radial loads



b) torque

Fig. 6. FEA results of polyurethane bushing.

The axial and radial and torsional stiffnesses can be determined from the result presented in Fig. 6.

Fig. 7 presents one of the experimental compression test performed on the bushing.

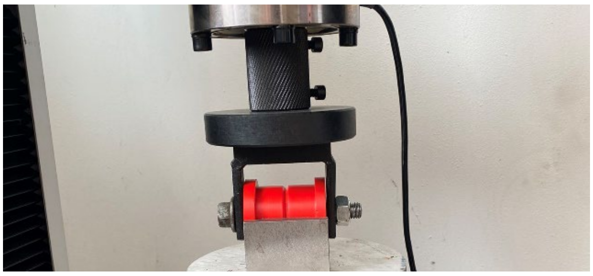


Fig. 7. Experimental compression test of polyurethane bushing.

Fig. 8 shows the variation of radial load versus displacement of the polyurethane bushing obtained from the compression test and FEA.

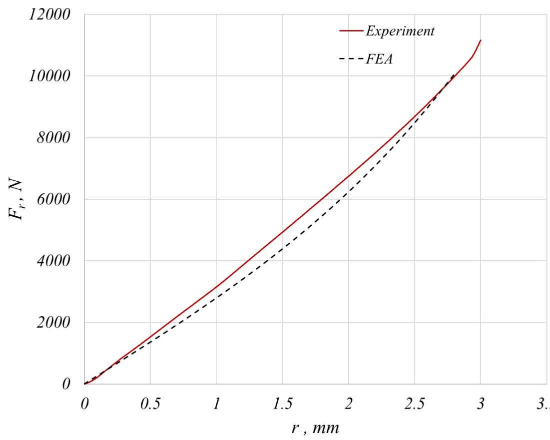


Fig. 8. Result of test and FEA of polyurethane bushing.

Table 2 presents the results for the static radial stiffness of the polyurethane bushing obtained by FEA and results obtained experimentally.

TABLE 2 RADIAL STIFFNESS

Radial Stiffness of Polyurethane Bushing, (N/mm)		**Deviation, %**
FEA	***Experimental***	
2922.6	3327.53	13.85

The results for radial stiffness obtained by FEA are close to the results obtained experimentally, with a maximum deviation of 14%.

IV. Conclusions

The study allows to make the follow conclusions:

The mechanical behavior of polyurethane was determined through experimental investigation of tensile strength. The stress-strain curve necessary for numerical analysis of the bushing was determined. The material hardness for the specimen and the bushing was 80 on the Shore A scale and was measured with a Shore A Durometer tester.

The results for the radial stiffness of the polyurethane bushing obtained through FEA closely match the experimentally obtained results, with a maximum deviation of 14%.

Following the conducted experimental investigation of the radial stiffness of the polyurethane bushing, it is recommended to use FEA for determining stiffness. The determined stiffness of the polyurethane bushing can be utilized for conducting various suspension analyses and related component studies. Additionally, they can serve for conducting comparative analyses between suspension setups using rubber and polyurethane bushings.

Acknowledgments

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