**Simulation and Comparing of Hyperelastic Models to Experimental Data in ABAQUS**

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**Abstract**

Hyperelastic models are essential for accurately capturing the nonlinear and incompressible behavior of elastomeric materials in finite element analysis. The purpose of current study is to examine the accuracy of various hyperelastic models, including Yeoh, Mooney-Rivlin, Neo-Hookean, Polynomial (N=2), Arruda-Boyce, Van der Waals, and Ogden, by applying experimental data from uniaxial tension, biaxial tension, and planar tension tests sourced from existing literature. The models use curve-fitting functions to determine parameters, addressing the difficulty of finite element models of elastomers, which have highly nonlinear stress-strain behaviour and near-incompressibility. Additionally, the precision of the simulations depends significantly on the selection of appropriate element types and formulations. By comparing the performance of these hyperelastic models against experimental data, this study provides insights into their effectiveness and aids in selecting suitable models for accurate finite element analysis of elastomeric materials. The objective is to identify an appropriate constitutive model based on strain energy potential to accurately describe hyperelastic material response. Using built-in constitutive hyperelastic models in ABAQUS, the study fits experimental results, assesses model stability, and derives necessary material coefficients, with the software optimizing the fit between test data and theoretical models. These efforts are aimed at enhancing the understanding and simulation precision of hyperelastic materials in various engineering applications. The study observed that the Ogden model, Mooney Rivlin, Van der Waals Model are showing good agreement with Abaqus for experimental tension test results.

***Keywords:*** *Hyperelastic, Curve-fitting, finite element analysis, Abaqus, strain-energy function*

**1 Introduction**

Rubber is renowned for its remarkable elastic properties, capable of stretching far more than metals—often up to 500%—and yet returning to its original shape without permanent deformation. This elasticity makes rubber highly resilient under varying loads, offering durability and flexibility in applications ranging from industrial components to biomedical devices. Moreover, rubber exhibits exceptional internal damping characteristics when subjected to dynamic forces. This damping ability allows rubber to efficiently absorb and dissipate energy, making it invaluable for applications where vibration and shock isolation are critical, such as in machinery mounts and automotive suspensions [1].

Hyperelastic material models perform an essential role in understanding and forecasting the mechanical response of the elastomers, foams, and biological tissues. These models are particularly essential for elastomers due to their nearly incompressible nature and their ability to withstand large deformations under tension, compression, and shear. Unlike metals and other materials, elastomers experience minimal volume changes during deformation, presenting a complex interplay of mechanical responses that require sophisticated modeling techniques to accurately simulate [2-3].

In engineering practice, hyperelastic models are crucial for finite element analysis (FEA), enabling engineers to simulate and predict how these materials will behave under various loading conditions. This capability is instrumental in designing and optimizing products across diverse industries such as aerospace, automotive, and medical fields. By accurately representing the non-linear stress-strain relationships and incompressibility of elastomers, these models help ensure product reliability, performance, and safety [4].

For instance, elastomeric bearing pads used in bridges serve a critical role in isolating vibrations and transferring loads between superstructures and substructures. Simulation tools like ABAQUS utilize constitutive models that require specific material coefficients, often derived from experimental tests like uniaxial, biaxial, and planar tension tests. These tests provide essential data to calibrate the models, though obtaining volumetric tension and compression data for incompressible materials like rubber remains a challenge. Nonetheless, accurate simulations enhance the effectiveness of elastomeric materials in practical applications, supporting advancements in engineering and medical technologies.

The present study of hyperelastic materials not only enhances our understanding of complex material behaviors but also facilitates innovation in product design and performance optimization. By leveraging advanced modeling techniques and experimental data, engineers can harness the full potential of elastomers and similar materials in creating safer, more efficient, and technologically advanced solutions for a wide range of industrial and biomedical applications. This study presented the strain energy function and equations of the different hyperelastic models and done the comparative study of the models using the curve fitting in Abaqus.

**2 Constitutive Equations for Hyper-elastic Material** [4-8]

Constitutive hyperelastic models are mathematical formulations used to describe how materials deform under various loads. Unlike linear elastic models, which are suitable for small deformations, hyperelastic models are designed to handle large, nonlinear deformations. These models are characterized by a strain energy density function, which represents the stored energy in the material as a function of the strain as shown in Table 1. The behaviour of rubber is like homogenous, isotropic, hyper elastic, and incompressible solids.

The strain energy density function (SEDF) is a scalar function that provides a measure of the energy stored in the material per unit volume due to deformation. It is the cornerstone of hyperelastic material models and is derived from the principles of continuum mechanics. The SEDF based on the deformation gradient, which describes the transformation from the reference configuration (undeformed state) to the current configuration (deformed state). This energy potential function is stated as a function of the strain at the specific point within the material. The elastic characteristics of rubber in terms of potential strain energy function in terms of Green's deviatoric strain invariants are as follows:

are first, second and third deviatoric strain invariant of the green deformation tensor in terms of .

Abaqus offers various types of strain energy potentials for modelling nearly incompressible isotropic elastomers, and these options are outlined below:

**Table 1** Shows the expression of the different hyperelastic constitutive models

|  |  |  |
| --- | --- | --- |
| **Strain Energy Function** | **Expressions** | **Parameters** |
| Aruda-Boyce strain energy potential Model | µ+ | Where |
| Marlow Model |  | is a deviatoric part of strain energy per unit volume and is volumetric part |
| Ogden Model [9] |  | - |
| Mooney-Rivlin Model [10] |  | - |
| Neo-Hookean Model |  | - |
| Yeoh Model [11] |  | For N=3, the equation can be written as: |
| Van der Waals Model | , | Where, and , = locking stretch, a= global interaction β= invariant mixture parameter, µ= shear modulus |
| Polynomial Model |  | Where and are temperature dependent parameter |
| Reduced Polynomial Model |  | , are material constant, N= material constant (positive numbers N=1,2,3) |

Where, µ, and D, are temperature dependent parameter; and and , where J= Jacobean determinant where, , , is the elastic volume ratio, K is bulk modulus. The and are constants which depends upon shear behaviour and is compressibility.

For design predictions to be relevant, it's crucial to determine material properties under conditions matching the intended service conditions. When using a combination of test data to calculate model coefficients, ensure that all tests are conducted using the same material at a consistent temperature. The commonly experiments include uniaxial tension, biaxial tension, and planar tension tests as shown in Table 2. After performing these tests and establishing stress-strain relationships for each mode, the program compares the results to a specific function, displaying an adjusted curve and calculating the necessary material coefficients. To clarify, ABAQUS software (as shown in Fig.1) is employed to simulate the test conditions for each of these tests, and then, essential simulation parameters are extracted.

**Table 2** Display the experimental findings for the uniaxial tension test, biaxial tension test, and planar test [12-13].

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Uniaxial Test Data** | |  | **Biaxial Test Data** | |  | **Planar Test Data** | |
| Stress (MPa) | Strain |  | Stress (MPa) | Strain |  | Stress (MPa) | Strain |
| 0.054 | 0.038 |  | 0.089 | 0.02 |  | 0.055 | 0.069 |
| 0.152 | 0.1338 |  | 0.255 | 0.14 |  | 0.324 | 0.2828 |
| 0.254 | 0.221 |  | 0.503 | 0.42 |  | 0.758 | 1.3862 |
| 0.362 | 0.345 |  | 0.958 | 1.49 |  | 1.269 | 3.0345 |
| 0.459 | 0.46 |  | 1.703 | 2.75 |  | 1.779 | 4.0621 |
| 0.583 | 0.6242 |  | 2.413 | 3.45 |  |  |  |
| 0.656 | 0.851 |  |  |  |  |  |  |
| 0.73 | 1.4268 |  |  |  |  |  |  |

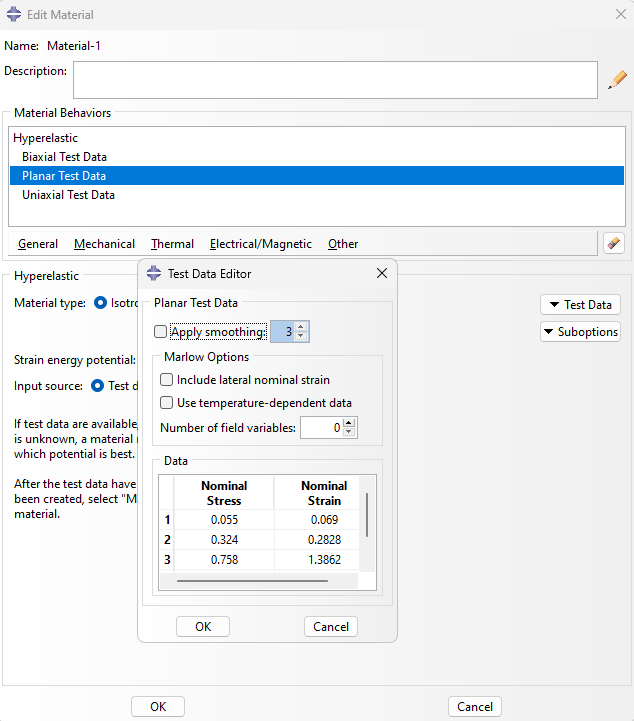


Fig. 1 Show the Abaqus view of applied experimental data

**3 Results and Discussion**

This study evaluated the accuracy of seven hyperelastic models—Yeoh, Mooney-Rivlin, Neo-Hookean, Polynomial (N=2), Arruda-Boyce, Van der Waals, and Ogden—using experimental data from uniaxial tension, biaxial tension, and planar tension tests as shown i9n Fig.2, Fig.3 and Fig.4, respectively. The study’s findings emphasize the importance of selecting appropriate hyperelastic models for finite element analysis to ensure accurate simulations and reliable performance of elastomeric materials in various implementations. This research offers crucial understandings for optimizing the design and analysis of elastomeric components, such as seismic isolation bearings, in engineering practice.

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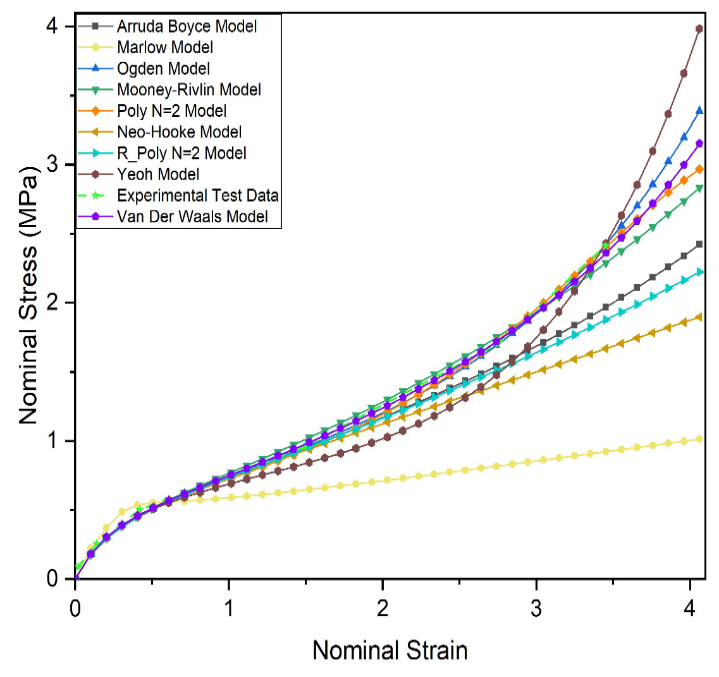


Fig. 3 Rubber biaxial test

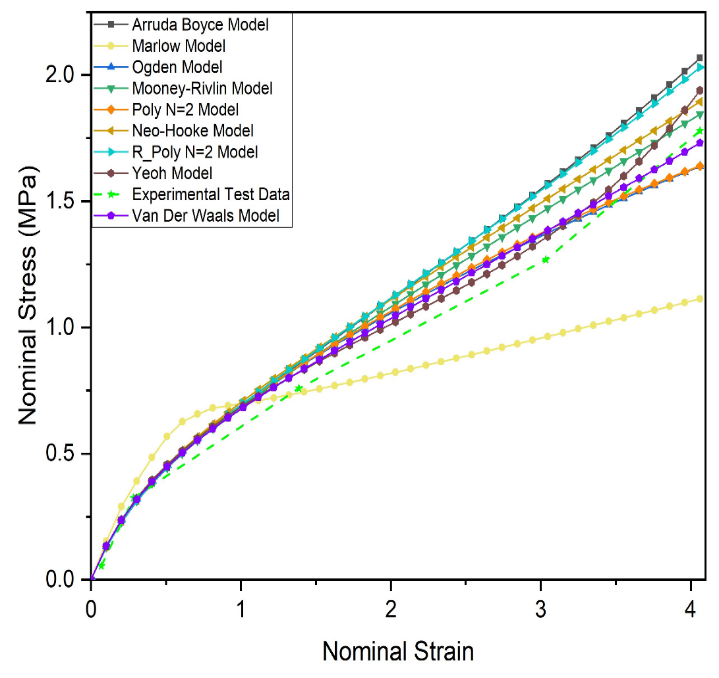


Fig. 4 Rubber planar test

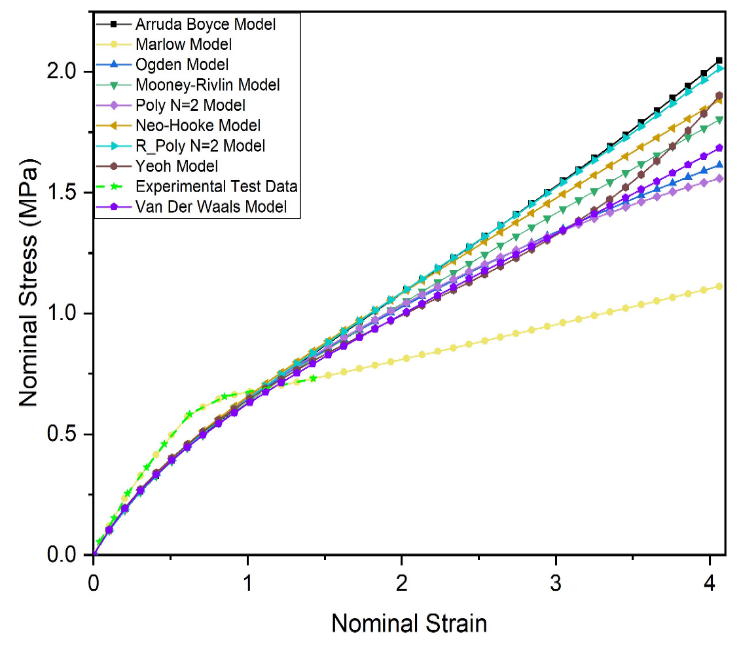


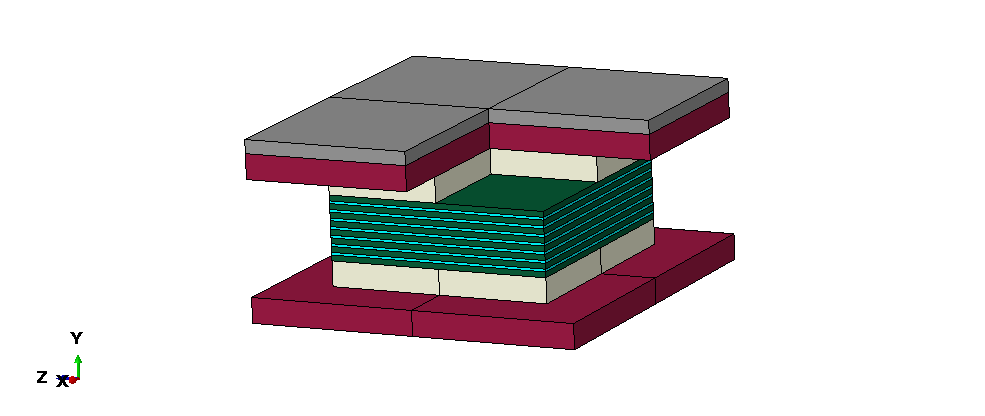
Fig. 2 Rubber uniaxial test

The material coefficients produced by the constitutive hyperelastic models are shown in the Material Parameters and Stability check information in Table 3. The coefficients involved are material constants that are classified into deviatoric and volumetric components for each of the models. The deviatoric coefficients are denoted as , , and whereas the volumetric coefficient is consistently zero due to the absence of input volumetric data from experiments. The material coefficients derived from the selected models can be applied as input data, effectively defining material characteristics for subsequent analyses and design processes, as illustrated in Table 3.

**Table 3** Determination of hyper-elastic constitutive model parameters and checks for stability.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Constitutive Model Function** | **Stability Check** |  |  |  |  |  |  |
| Yeoh | Stable | 0.190359 | - | - | -0.00196593 | - | 0.0000562 |
| Mooney-Rivlin | Stable | 0.17855139 | 0.0039558 | - | - | - | - |
| Neo-Hookean | Stable | 0.1873775 | - | - | - | - | - |
| Polynomial | Unstable | 0.188151 | -0.0010692 | 0.00026280 | -0.0007801 | -0.0000086 | - |
| **Constitutive Model** |  |  |  |  |  | **-** | **-** |
| Arruda-Boyce | Stable | 0.3589605 | 6.843303 | - | - | - | - |
| Van der Waals | - | 0.380356 | 18.90983 | 0.130183 | 0.02576303 | - | - |
| **Constitutive Model** |  |  |  |  |  |  |  |
| Ogden | Stable | -2.92358 | 2.50403 | 2.22788 | 0.0009928 | -0.322724 | 0.6965774 |

The hyperelastic material coefficients obtained from the curve fitting method have broad applications across various fields, particularly in the development of effective seismic base isolation bearings. These bearings play a crucial role in reducing the damaging effects of earthquake forces on buildings, bridges, and other critical structures. By incorporating hyperelastic materials with precisely determined coefficients, engineers can design isolation systems that enhance the resilience of structures, thereby safeguarding lives and property during seismic events. The integration of such advanced materials into seismic isolation technology represents a significant advancement in protecting infrastructure and ensuring the safety of occupants during earthquakes. The schematic representation of the rectangular high damping rubber bearing (as shown in Fig. 5), where steel and rubber layers are attached by vulcanization process.



End Plate

Top Loading Plate

Top Fixing Plate

Rubber Layer

Steel Layer

Bottom Loading Plate

Bottom Fixing Plate

Fig.5 Shows the schematic diagram of rectangular elastomeric rubber bearing with its components

**4 Conclusion**

Hyperelastic material models are crucial in the FEA of elastomers and similar materials. They enable the accurate prediction of material behavior under complex loading conditions, which is essential for designing reliable products in industries such as automotive, aerospace, and biomedical engineering. By accurately representing the nonlinear stress-strain behavior and incompressibility of elastomers, these models help engineers optimize material performance, enhance product durability, and ensure safety in various applications.

In summary, constitutive hyperelastic material models and their associated strain energy density functions are vital tools for understanding and predicting the behavior of elastomeric materials. Through sophisticated mathematical formulations, these models capture the intricate response of materials subjected to large deformations, enabling precise and reliable design and analysis in engineering applications.

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