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Experimental determination of the Mooney–Rivlin model for hyperelastic materials like rubber

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Abstract
Rubber-like hyperelastic materials are widely used in many engineering fields. In order to correctly assess the behaviors of rubber-made structures, constitutive models of materials are critical. According to International Standard ISO 37:2005, tensile experiments were done using M350-10kN-type apparatus. And then the Mooney-Rivlin parameters using experiment data are obtained under two different deformation. The results show that experimental process was quite reliable. It could provide the credible parameters of Mooney-Rivlin model to the further use the results in numerical analyses of rubber-made structures.

Keywords: hyperelastic material; mooney-rivlin model; stress and strain; vibration and noise

Introduction

Rubber-like materials are widely used in mechanical engineering, construction engineering, automobile industry, engineering vehicles, railway vehicles, navigation ships, aerospace and other industrial fields to reduce vibration and noise [1, 2]. Unlike common metal materials, rubber-like materials belong to isotropic and incompressible hyperelastic materials with complex characteristics such as material non-linearity and geometric non-linearity. Therefore they cannot be described by simple mathematical models. At present, different researchers mainly describe them through two types of constitutive models including the molecular-statistical model and phenomenological model [3, 4].

Given the typical nonlinear retardation behavior of the stress-strain relationship of rubber-like materials, a reasonable constitutive model is the precursor to the characterization of its properties. Phenomenological model cover Neo-Hooke, Mooney-Rivlin, Yeoh, Ogden, Gent and so on [5]. Mooney-Rivlin model could be adopted only when hyperelastic rubber-like materials under deformations are isotropic and the shear deformations meet Hooke law. At the same time, it can use two, five or nine parameters.

Two parameters of the Mooney-Rivlin model are obtained using the experiment or experience method [6, 7]. The experience method is based on a large number of previous tests. The test data are analyzed and calculated and then the general law between the model parameters and its characteristics of the rubber material can be obtained. Due to many influencing factors of the empirical method, the material constants determined according to it is usually not as accurate as the test method. However, the empirical method has been widely recognized and applied by engineers and researchers with its advantages of simplicity, both efficiency and precision.

The purpose of this paper is to determine the Mooney-Rivlin parameters using experiment in order to evaluate the stress and strain state of rubber materials. According to International Standard ISO 37:2005, tensile experiments were done using M350-10kN-type apparatus.

Material and Methods

Uniaxial tensile experiments are a common method to obtain the static mechanical properties of rubber-like materials. When a constant load was applied to both ends of a sample with a specific shape, the stress-strain relationship was recorded under this load. According to International Standard ISO 37:2005, tensile experiments were done using M350-10kN-type apparatus. The room temperature was chosen to be 25°C. The sample dimensions were 45mm×25mm×2.3mm. The tensile rate was 10 mm/min. The specimens and the testing machine were shown in Fig.1.

The mechanical behaviors of specimens under different deformations of 0~100% and 0~350% are discussed below.

Under deformation 0~100%, the specimens were subjected to two times of loading tests. The stress-deformation relationship curves measured by the M350-10kN-type apparatus were shown in Figure 2.

Considering that two curves measured in the above two tensile tests are relatively close, Matlab software is used in this paper to process data according to the least square principle, and the fitting line is finally obtained as shown in Figure 3. The mathematical expression is, therefore, the M-R constants of Mooney-Rivlin model are C_{10}=1.81 and C_{01}=1.57.

Under large deformation 0~350%, the specimens were subjected to three times of loading and unloading tests under the same conditions, and the stress-deformation relationship curves obtained were shown in Figure 4. In addition, it could be known from Fig. 4 that when the tensile stress is close to zero, there is still residual strain. This phenomenon is caused owing to two factors: one is that the lower fixture of the specimens is loosened to some extent due to the influence of heavy load, the other is that the rubber-like materials belong to a kind of macro-molecule material, and the strain lags behind the stress.

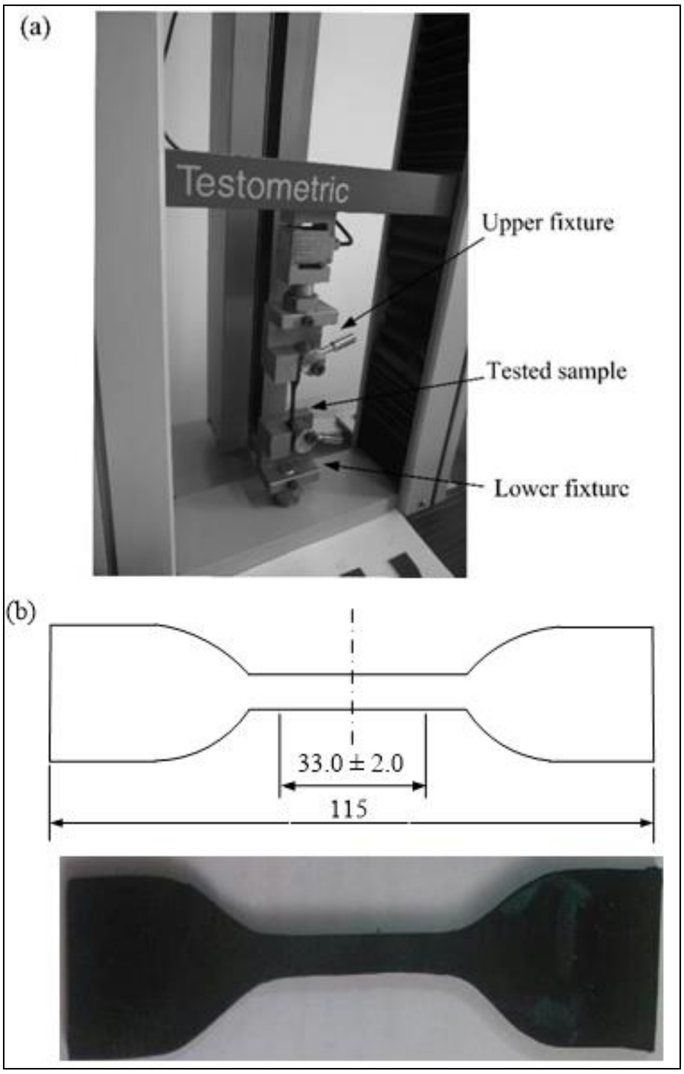

Fig. 1: Specimens and the testing machine

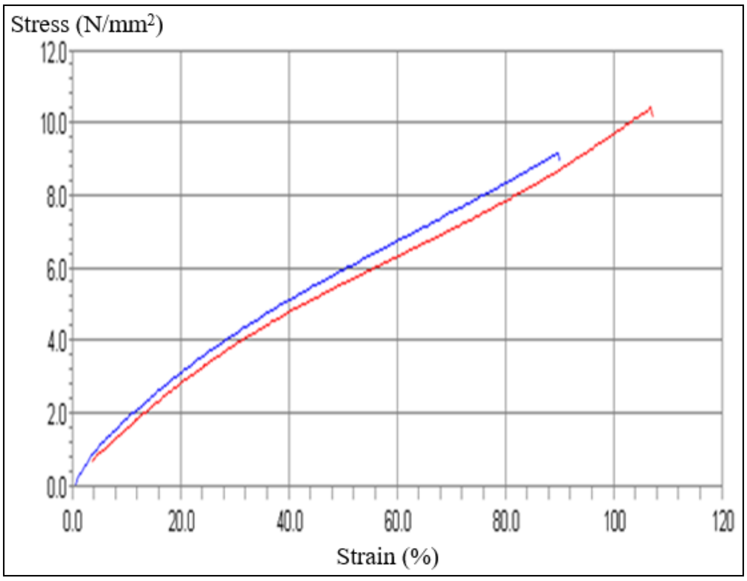

Fig 2: Uniaxial tension curve of rubbe-like sample with low strain

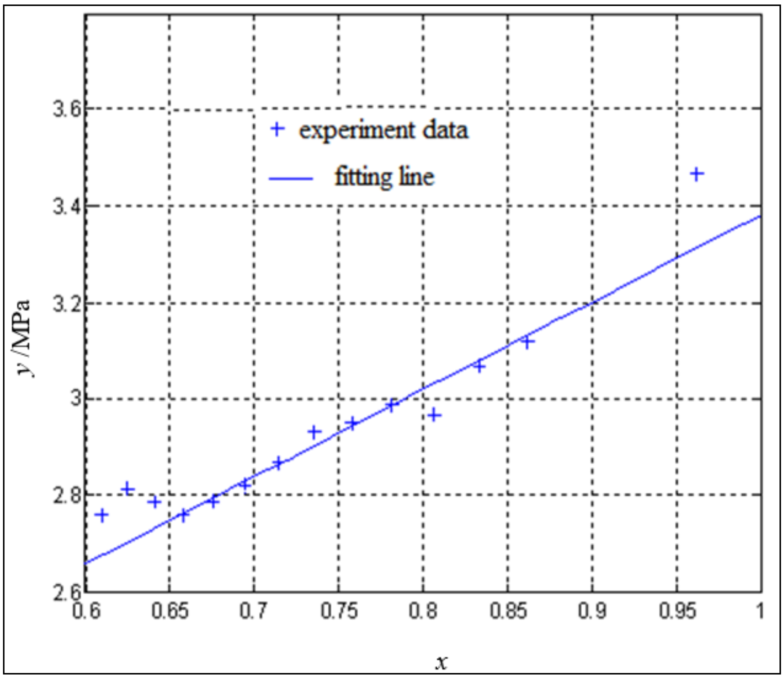

Fig 3: Fitting curve of rubber-like material constants (low strain)

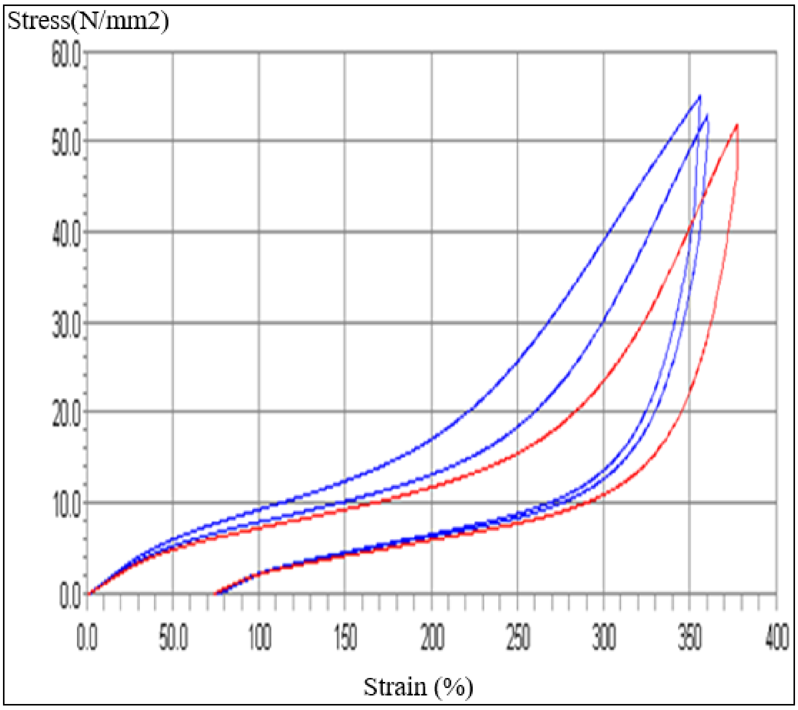

Fig 4: Stress-strain curves of rubber-like sample with large strain

Likely with the above data fitting method, the fitting line is finally obtained as shown in Figure 5. The mathematical expression is $y = 1.81 + 1.62x$, therefore, the M-R constants of Mooney-Rivlin model are C_{10}=1.81 and C_{01}=1.62.
Further comparative analysis of test results in Figure 3 and Figure 5 shows that the experimental process was quite reliable. The average values of C10 and C01 were taken respectively, that is, C_{10}=1.81 and C_{01}=1.595.

Conclusions

In this paper, using experiments, the M-R constants of Mooney-Rivlin model are obtained. Through the above researches, the main results are given as follows:

1. Under deformation 0~100%, the M-R constants of Mooney-Rivlin model are C_{10}=1.81 and C_{01}=1.57
2. Under large deformation 0~350%, the M-R constants of Mooney-Rivlin model are C_{10}=1.81 and C_{01}=1.62.
3. The final parameters of Mooney-Rivlin model are chosen to be C_{10}=1.81 and C_{01}=1.595.

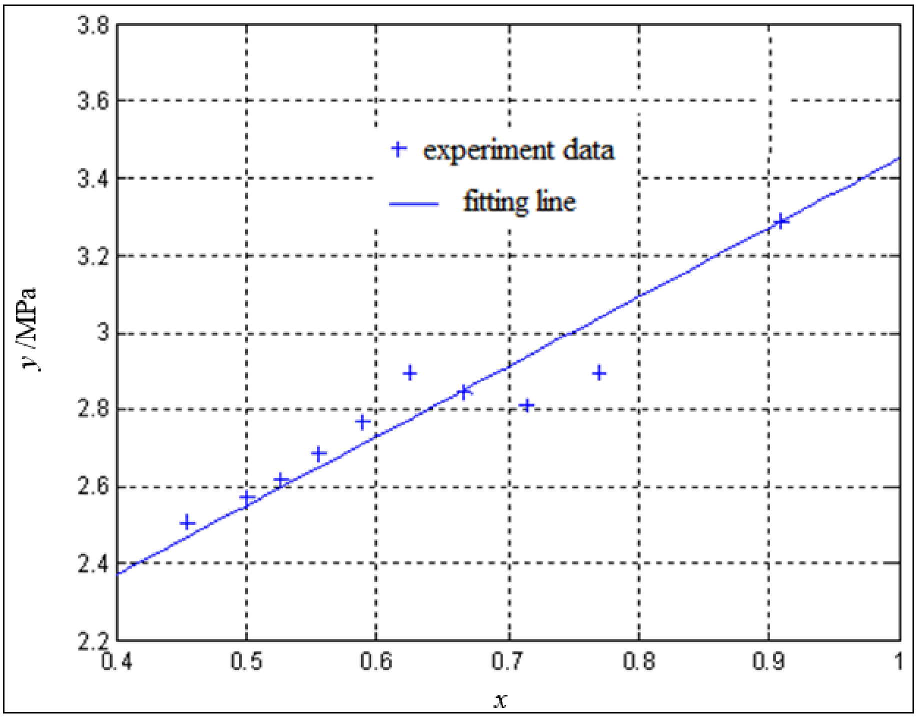

Fig 5: Fitting curve of rubber material constants (large strain)

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