Finite element analysis of rubber material cross specimen based on ANSYS Workbench

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Abstract. The finite element analysis software ANSYS Workbench was used to fit and analyze the Ogden constitutive model, and the effect of the arm seam and its parameters on the stress distribution uniformity in the central test area was simulated and analyzed. The results show that different chamfering radii and the number of arm seams have an effect on the stress distribution in the center test area of the sample. The chamfering radius of 1.5mm in the center test area has a high uniformity of uniform stress distribution and a small degree of stress concentration. As the number of arm seams increases, the uniform stress distribution in the central test area increases slightly. This study can provide a reference for the preparation of standard specimens for bidirectional tensile testing of rubber materials.

Keywords: ANSYS Workbench. Rubber material, finite element.

1. Introduction
Rubber is a polymer compound with high elasticity. Due to its good performance, it is widely used in industrial fields, such as locomotives, automobile passenger cars, aviation defense, medical treatment, etc. Rubber materials have a large deformation range, strong bearing capacity and good performance are widely used in various fields [1-3]. In order to characterize the true mechanical properties of rubber materials, domestic and foreign research scholars have conducted various basic mechanical experiments on rubber materials, but the uniaxial tensile, planar tensile and compression test data alone are not sufficient for constitutive when they are subjected to complex stress conditions. The model provides reliable parameters. Moreover, it is difficult to solve the stress-strain relationship by constructing an accurate mathematical model. Secondly, in the field of rubber materials, there is no uniform standard for the shape of the sample. After consulting domestic and foreign literatures, it is found that using ANSYS Workbench finite element analysis software to simulate the cross-shaped sample is relatively rare. Therefore, it is of great practical significance to study the stress-strain characteristics of materials under bi-directional tension to obtain more accurate mechanical performance parameters.

2. Phenomenological constitutive model based on strain energy density function
Rubber has mechanical properties such as superelasticity, wear resistance, insulation and barrier properties, and has been widely used in the engineering field [4]. The research on the constitutive model of rubber materials can be traced back to the 1940s, due to its complex The molecular properties and the double nonlinearity of materials and geometry have made it impossible to establish an accurate
constitutive mathematical model. The unique constitutive behavior of rubber materials has always been the research interest of many mechanics and engineers[5,6]. Constitutive models can be divided into two major categories[6]: One is a molecular chain network model based on statistical thermodynamics, such as Gaussian network model, 3 (4) chain network model, 8-chain network model and full chain network model, etc.; One type is phenomenological models based on the assumption of continuum, such as Rivlin model, neo-Hookean model, Mooney-Rivlin model, Yeoh model, Ogden model, Gent model, Valanis-Landel model, etc. The above models have applicability, but lack Analysis of the physical mechanism of its advantages and disadvantages [7].

Ogden believes that using strain invariant I to construct the strain energy density function in the existing constitutive model will produce a more complex conversion relationship, and the stretch ratio is a quantity that can be directly measured, so it is proposed to use the stretch ratio $\lambda$ as the independent variable Strain energy density function:

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

(1)

Where: material constants $\mu_i$ and $\alpha_i$ describe the shear properties of the material; $N$ is the order. In particular, when $N = 1$, $\alpha_1 = 2$, $\alpha_2 = -2$, it can be regarded as a special expression form of Mooney-Rivlin model. From the perspective of finite element analysis, if the selected model can accurately describe the behavior of rubber materials through reasonable fitting parameters, the function form can be based on strain invariant or stretch ratio.

The experimental data was fitted to the 3-order Ogden constitutive model by ANSYS, and the results are shown in Figure 1.

Figure 1. Fitting results of Ogden constitutive model

It can be seen from the figure that the experimental curve and the fitting curve are basically consistent, and the Ogden model has a large strain range applicability. Therefore, the Ogden 3rd order constitutive model is used to simulate and analyze the behavioral characteristics of rubber materials under different tensile and compression conditions, resulting in smaller errors.

The order $N$ of Ogden constitutive model can be 1-6. Studies have shown that when the order taken increases, the analysis accuracy of the model will be correspondingly improved, but at the same time it will cause the accumulation of errors in the analysis, which leads to the difficulty of convergence in the finite element simulation analysis. Generally, when the model is selected, the value of $N$ is less than 4. When the order is low, the calculation accuracy cannot meet the requirements, and it is more difficult to fit the high-order constitutive equations containing multiple parameters; the practical value of the strain energy density function with the order $N$ of more than 4 is not high. Therefore, Ogden 3-order constitutive model is often used in engineering analysis and calculation [8].

3. Establishment of a finite element model of a cross-shaped specimen with open arms

Using the geometric model parameters in [9], and using the mathematical model of the open-arm-slit cross-shaped specimen established by SolidWorks, the geometric shape of the specimen is relatively simple. The three-dimensional model only needs to be obtained by stretching. The size of the model including: the overall size of the open-arm slit cross-shaped sample is 120mm×120mm; the thickness is 2mm; the size of the clamping area is 15mm×30mm; the square area of the central area is 30mm×30mm.
Taking a cross-shaped specimen with an arm gap width of 1 mm as an example, due to the symmetry of the model, symmetric boundary conditions can be applied to the left, bottom and thickness of the model, and 10N are applied to the edges of the two cross tensile arms Cloth load.

4. Influence of arm seam and its parameters

The parameters of the open arm seam cross-shaped sample are as follows: the overall size of the sample is 120mm×120mm; the radius of the fillet is 1.5mm; the thickness of the sample is 2mm; the clamping area is 15mm; the center area is 30mm; the length of the arm seam is 20mm, and the width of the arm seam is 1mm; the number of uniformly distributed arm seams is 3, 5 and 7 respectively.

4.1. The maximum deformation of the center test area of the cross-shaped sample with open arm seam

In the simulation analysis, when the load ratio of the two arms is 1:1, the X-axis normal strain $\varepsilon_x$ in the central test area is greater than the Y-axis normal strain $\varepsilon_y$, and the maximum deformation is taken as $\varepsilon_x$; when the added two-arm load ratio is 1:2 o'clock, the Y-axis normal strain $\varepsilon_y$ in the central test area is greater than the X-axis normal strain $\varepsilon_x$, and the maximum deformation is taken as $\varepsilon_y$.

Whether the load ratio is 1:1 or 1:2, the maximum deformation of the center test area of the specimen will increase with the increase in the number of arm seams. And the increase of the number of arm seams can effectively increase the deformation of the central test area. When the load ratio is 1:2, the maximum deformation in the central test area is greater than when the load ratio is 1:1.

4.2. Influence of the number of arm seams on the stress and strain distribution in the central test area

The length of the arm seam is 20mm, the width of the arm seam is 1mm, and the chamfer of the stretching arm is 1.5mm. On the stretching arm, 3, 5, and 7 uniformly distributed arm seams are limited at a load ratio of 1:1. Meta-analysis calculation. The equivalent stress distribution cloud diagram of the cross-shaped specimens with different number of arm slits after loading and deformation is shown in Figure 2.

![Figure 2. Equivalent stress nephogram of samples with different number of arm seam](image-url)
It can be seen from the equivalent stress cloud diagram that with the increase in the number of arm seams, the uniformity of the equivalent stress distribution in the center test area of the deformed specimen shows a slightly increasing trend, and the stress value does not change significantly. The change trend of the equivalent stress distribution of the samples with different number of arm slits in the central test area is roughly the same, and the stress value will be large in the area close to the arm slit. Therefore, from the analysis of the stress cloud diagram, it can be concluded that the number of arm seams of 3 is more in line with design requirements.

In summary, from the analysis of the equivalent stress cloud diagram, it can be concluded that the increase in the number of arm seams does not change the equivalent stress distribution of the sample in the central test area, but as the number of arm seams increases, it will increase the stress value of the tensile arm.

For the same reason, the equivalent strain distribution of the center test area of the samples with different numbers of arm seams after loading deformation is shown in Figure 3.

![Figure 3.](image)

From the analysis of the equivalent strain distribution in the center test area of the sample with three different numbers of arm slits in Figure 3, it can be concluded that with the increase in the number of arm seams, the uniformity of the strain distribution in the center test area of the deformed specimen is more. The trend is good, but with the increase in the number of arm seams, the strain value at the arm seam of the entire tensile arm shows an increasing trend. Therefore, considering the overall size of the tensile arm of the sample, the number of open arm seams should not be too many, and it is better to choose three.
5. Variation of stress in specimens with different chamfering radii under different tensile conditions

The parameters of the open-arm seam cross-shaped sample used are as follows: the overall size of the sample is 120mm×120mm; the thickness of the sample is 2mm; the clamping area is 15mm; the central area is 30mm; the length of the arm seam is 20mm; three uniformly distributed The gap of the arm; the radius of the chamfer at the stretch arm is 1mm, 1.5mm, 5mm and 10mm respectively for simulation analysis.

The cross-shaped sample of the split arm slit is loaded and stretched in one direction, and the equivalent stress at the stretch arm chamfer radius is 1mm, 1.5mm, 5mm and 10mm respectively as shown in Figure 4.

![Figure 4. Equivalent stress of different chamfering radius](image)

It can be seen from the equivalent stress cloud diagram that during unidirectional stretching, as the radius of the chamfer at the tensile arm increases, the stress at the radius of the arm seam increases first and then decreases. The center of the sample after deformation The uneven distribution of stress in the test area becomes larger. The stress concentration at the corner of the arm seam perpendicular to the load direction is the largest during unidirectional stretching.

The cross-shaped specimen with split arm slits is loaded at a ratio of 1:1 along the X axis and the Y axis. The equivalent stress at the tensile arm is 1mm, 1.5mm, 5mm, and 10mm respectively as shown in Figure 5.
Figure 5. Equivalent stress of different chamfering radius

From the equivalent stress cloud diagram, it can be seen that during equal bidirectional stretching, as the radius of the chamfer at the tensile arm increases, the stress concentration transitions from the chamfer of the tensile arm to the radius of the arm seam and the stress continues increased, the uniform stress distribution in the center test area of the deformed specimen spread to the chamfer of the tensile arm. The increase in the radius of the chamfer can improve the stress concentration at the connection between the two tensile arms, but the degree of stress concentration at the fillet of the arm gap increases. When the chamfering radius at the tensile arm is 1 mm, the stress concentration is less than the chamfering radius of 1.5 mm, but the uniformity of the equivalent stress distribution in the central test area is poor. Considering that the radius of the chamfer is 1.5 mm when the specimen is stretched in two directions.

6. Conclusion

(1) During iso-biaxial stretching, the chamfering radius at the stretching arm is 1.5 mm. The central test area has a high uniformity of equivalent stress distribution and a relatively small degree of stress concentration.

(2) When the number of arm slits is 3, 5, or 7, the uniform range of stress and strain distribution in the central test area increases slightly as the number of arm slits increases. Taking into account the overall size of the tensile arm of the sample, the number of arm seams should be 3.

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