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Effect of Pattern Block Stiffness on Tire Wear Resistance

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***Abstract* – This study focuses on the influence of pattern block stiffness on tire wear resistance. The Yeoh model was selected to describe the constitutive relationship of the pattern block rubber material, and the parameters were obtained by uniaxial tensile test of the tire tread rubber sample. The common geometric parameters of tread pattern were selected as the optimal objects, including transverse groove depth, transverse groove wall angle and longitudinal groove wall angle. Numerical experiments were designed by orthogonal test method. The finite element software Abaqus was used to simulate the pattern block, and the ground pressure skewness value was selected to evaluate the wear resistance of the pattern block. The numerical test results showed that the transverse groove wall angle had a great influence on the ground pressure distribution. Moreover, the wear resistance of the pattern block increases with the increase of the longitudinal stiffness. Finally, it was concluded that the longitudinal stiffness of the pattern block had a great influence on the wear resistance during the slip. Therefore, reasonable design of the pattern block could appropriately increase longitudinal stiffness, which could improve the wear resistance of the tire.**

***Keywords* – Stiffness of Pattern Block, Wear Resistance of Tire, Finite Element Simulation, Longitudinal Stiffness.**

I. INTRODUCTION

Tire tread wear is an important factor that affects not only the service life but also the handling stability. As a component of the tire, tread pattern directly contacts with the road surface. In the rolling process, the deformation of the pattern block directly affects the ground pressure distribution and wear resistance of the tire.

A lot of studies devoted to tire wear. Hofstetter et al. established a finite element model of a single pattern block, which was used to analyze the deformation, grounding pressure distribution and wear of the pattern block during sliding, and obtained the irregular wear characteristics of the pattern block [1]. Wu et al. established a single-pitch pattern block model to study the influence of pattern groove angle and groove bottom curvature radius on ground pressure. Through the above analysis results, they studied the influence of pattern block grounding pressure distribution on tire wear resistance. The results showed that the pattern blocks with more uniform grounding pressure distribution had better wear resistance [2]. Maitre et al. used statistical principles to study the major factors of tire wear from both subjective and objective perspectives [3]. Based on the geometric update method, Shunkai Xu used Abaqus software to compare and analyze the wear resistance of smooth tires, longitudinal groove pattern tires and complex pattern tires, the results showed that the wear resistance of complex tread tires was poor [4]. By summarizing the achievements of the researchers, it is found that the pattern block is the main part that affects the wear.

Therefore, the finite element simulation software Abaqus was used in this study to model and simulate the pattern block, and analyze the influence of the pattern block stiffness on tire wear resistance.

II. EXPERIMENTS

The rubber material used in this study was tread rubber of 205 / 55R16 radial tire. In order to obtain the stress-strain curve of rubber material, uniaxial tensile test was carried out. As shown in Figure 1, the test equipment was GOTECH AI-7000M electronic tensile testing machine. The experimental environment temperature was 23 ± 2^{0}C, the tensile rate was 1% per second, and the strain order was 100%. In order to improve the accuracy of the test data, three rubber samples were made and used in the repeated tensile test for three times, and the mean values were obtained. As shown in Figure 2, the rubber sample was dumbbell type of national standard with its thickness, width and standard distance were 2 mm, 6 mm, and 25 mm, respectively [5]. Table 1 shows the stress-strain data of rubber materials obtained from the tensile test.

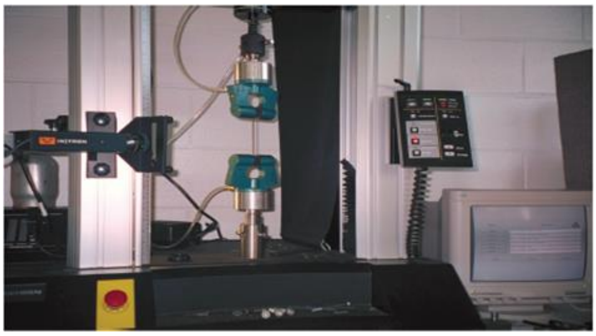


Fig. 1. Electronic tensile testing machine.

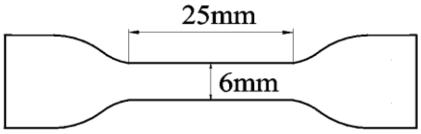


Fig. 2. Schematic diagram of rubber sample.

Table 1. Stress and strain data for rubber materials.

Strain (%)	Stress (MPa)	Strain (%)	Stress (MPa)
0	0	0.55	1.0926
0.05	0.2227	0.60	1.1628
0.10	0.3763	0.65	1.2359
0.15	0.5053	0.70	1.3138
0.20	0.6075	0.75	1.3995
0.25	0.6882	0.80	1.5067
0.30	0.7626	0.85	1.6345
0.35	0.8319	0.90	1.7883
0.40	0.8976	0.95	1.9421
0.45	0.9675	1.00	2.0959
0.50	1.0300		

III. FINITE ELEMENT MODEL OF PATTERN BLOCK

A. *Material model*

Rubber used in tires is nonlinear and incompressible material, with complex force-deformation relationship [6]. In this study, the Yeoh model with good precision and stability was selected to describe the mechanical properties of rubber materials [7]. Yeoh model was a third-order reduced polynomial model, which could well fit the shaped stress-strain curve of rubber materials [8]. Its strain energy density function is:

$$W = C_{10}(I_1 - 3) + C_{20}(I_1 - 3)^2 + C_{30}(I_1 - 3)^3 \tag{1}$$

Where W is the strain energy; C_{10}, C_{20} and C_{30} are the deformation tensor; I_1 is the first invariant of strain.

In formula (1), C_{10} represents the initial shear modulus, which has a great influence on the stress-strain of rubber material at small deformation. C_{20} is negative value, indicating the softening of the curve, which has a great influence on stress-strain of rubber material at medium deformation. C_{30} is a positive value, indicating the hardening of the curve, which has a great influence on the stress-strain of rubber material at large deformation [9]. Therefore, Yeoh model has a good ability to simulate large deformation of rubber.

The stress-strain data of tensile test were fitted with the fitting tool provided by Abaqus [10]. The fitting curve is shown in Figure 3, and the Yeoh model parameters of rubber material obtained by fitting are $C_{10} = 0.64382$, $C_{20} = -0.1736$ and $C_{30} = 0.0572$.

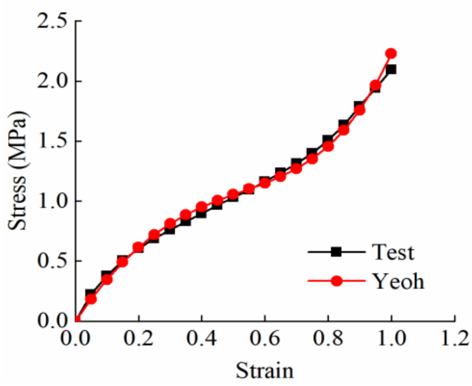


Fig. 3. Stress-strain fitting curve of rubber materials.

B. *Finite Element Model*

In this study, the finite element model of a single pattern block was established by Abaqus. The model size is shown in Figure 4.

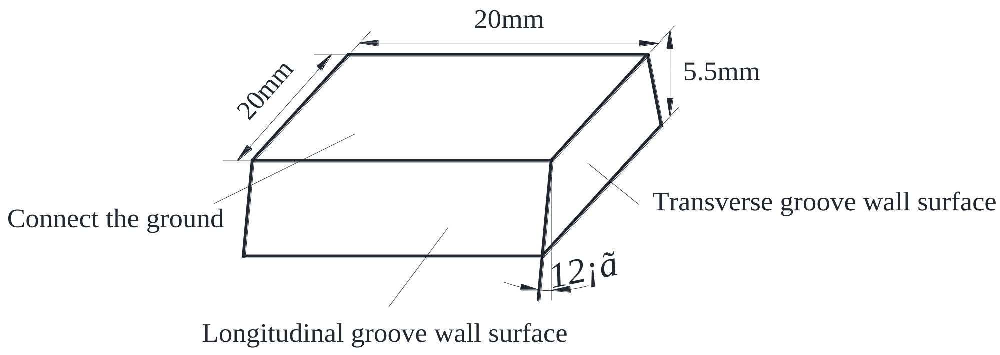


Fig. 4. Schematic diagram of pattern block model size.

The designed pattern block was meshed in Abaqus. In order to reduce the calculation cost and improve the calculation accuracy of the model, the pattern block grids near the ground area were refined, as shown in Figure 5. The road surface in the model was an analytical rigid body, and the number of cells and nodes in the model were 1561 and 2017, respectively.

Load and boundary conditions we applied to the model. The bottom surface of the pattern block was completely fixed. Firstly, the upward displacement was applied to the road surface in order to contact with the pattern block. Then the upward concentrated force 100 N was applied to the road surface to simulate the static loading of the pattern block. On the basis of static loading, a horizontal velocity 5 mm/s was applied to the road surface to simulate the sliding friction of the pattern block [11]. Figure 6 shows the results of ground pressure distribution.

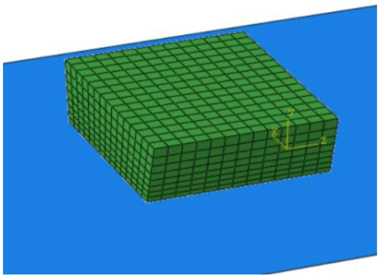


Fig. 5. Finite element model of pattern block.

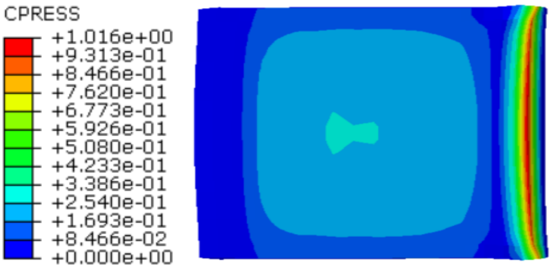


Fig. 6. Ground pressure distribution when the pattern block slips.

IV. ORTHOGONAL EXPERIMENTAL

In the design of tire pattern, there were many geometric design parameters. Among them, the main parameters affecting the deformation stiffness of tire pattern block were transverse groove depth, longitudinal and transverse groove shape [12]. Therefore, the influence of the deformation stiffness of the tread pattern on its grounding characteristics was three aspects: transverse groove depth, longitudinal groove wall angle and transverse groove wall angle.

The wear resistance of the pattern block was evaluated by using the grounding pressure distribution uniformity between the pattern block and the road surface [13]. With the increase of the uniformity of grounding pressure distribution, the wear resistance of the pattern block is improved, and vice versa. The distribution uniformity of grounding pressure is described by the value of grounding pressure skewness. The smaller the skewness, the more uniform the grounding pressure distribution will be. The calculation formula is as follows [14].

$$\alpha = \sqrt{\frac{1}{n-1}\sum\left(P_i - \overline{P}\right)^2} \tag{2}$$

Where P_i is the grounding pressure value of the i point in the pattern block grounding region; $\overline{P}$ is the average value of the grounding pressure; n is the number of nodes.

The orthogonal test method was adopted for numerical test. The test factors were transverse trench depth (A), longitudinal trench wall angle (B) and transverse trench wall angle (C). As shown in Table 2, three levels for each factor were selected. Among them, 5.5mm, 12° and 0° were the original parameters of 205/55R16 radial tire. L9(3^4) orthogonal table was used to arrange test, and 9 groups of combinations were tested.

Table 2. Code and level of factors chosen for the trials.

Level	**Factor**		
	A(mm)	**B(°)**	**C(°)**
1	4.5	8	0

Level	Factor		
	A(mm)	B(°)	C(°)
2	5.5	12	4
3	6.5	16	8

V. RESULTS AND DISCUSSION

The test analysis results are shown in Table 3. It can be concluded that the grounding pressure skewness value of Test 6 is the largest, and the combination is 5.5mm, 16° and 0°. The grounding pressure skewness value of Test 7 is the minimum, and its combination is 6.5mm, 8° and 8°. The extreme value *R* can determine the significance of factors to the target. If the *R* value is larger, the influence of this factor on the target is greater.

Table 3. L9(3^4) orthogonal test results.

Plan	Test	Test influencing factor			Ground pressure skewness (MPa)
		A (mm)	B (°)	C (°)	
1	1	4.5	8	0	0.2033
2	2	4.5	12	4	0.1840
3	3	4.5	16	8	0.1652
4	4	5.5	8	4	0.1847
5	5	5.5	12	8	0.1663
6	6	5.5	16	0	0.2036
7	7	6.5	8	8	0.1564
8	8	6.5	12	0	0.1873
9	9	6.5	16	4	0.1727
	K_1	0.184	0.181	0.198	
	K_2	0.185	0.179	0.180	
	K_3	0.172	0.180	0.163	
	R	0.013	0.002	0.035	

According to the data in Table 3, the transverse groove wall angle has the greatest influence on the grounding pressure distribution of the pattern block. The main effect diagram of A, B and C is shown in Figure 7. It can be seen that the wear resistance of the pattern block does not change obviously with the increase of transverse groove depth and longitudinal groove wall angle, but it increases rapidly with the increase of transverse groove wall angle. It can be concluded from the above analysis that the influence of transverse groove wall angle on the wear resistance of tire pattern is more significant than other factors.

Figure 8 shows the influence of transverse groove wall angle on the pattern stiffness obtained by finite element simulation. According to the figure, the longitudinal stiffness of the pattern block increases greatly with the increase of the transverse groove wall angle, while the transverse and radial stiffness increases less. It is concluded that the change of the longitudinal stiffness of the pattern block has a great influence on the wear resistance of the tire.

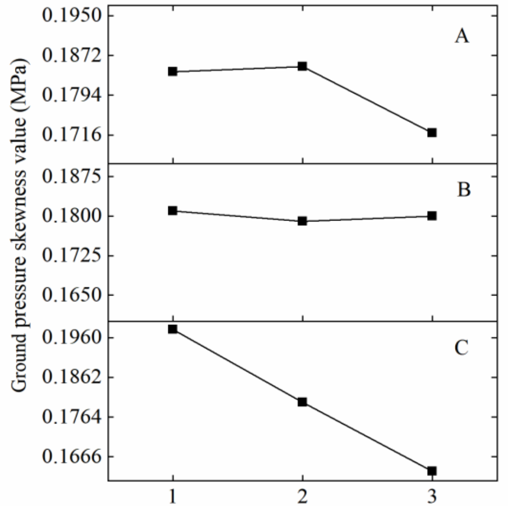
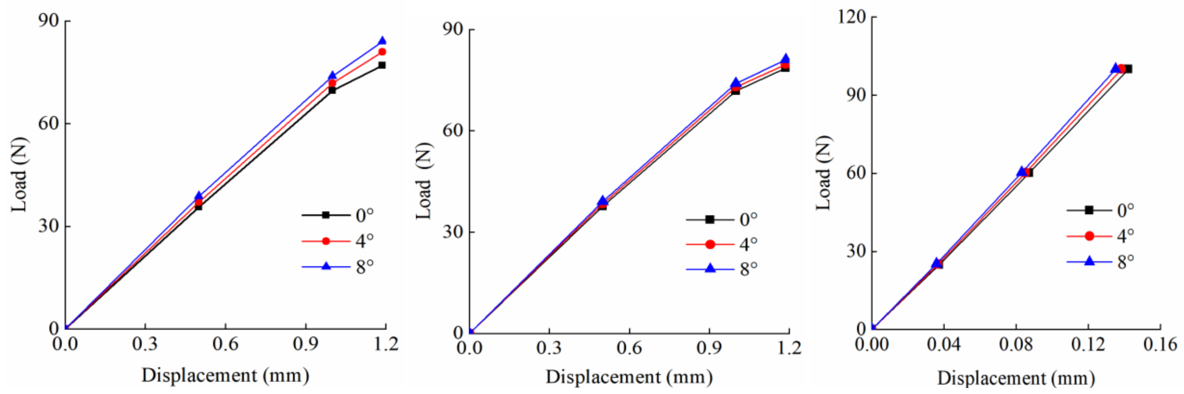


Fig. 7. The main effect diagram of A, B and C.



(a) Longitudinal stiffness

(b) Transverse stiffness

(c) Radial stiffness

Fig .8. Stiffness change curve of pattern block.

VI. CONCLUSION

In this study, the finite element model of a pattern block from 205/55r16 radial tire was established by using Abaqus. The influence of three structural parameters on wear resistance were numerically analyzed by orthogonal test method, with conclusions as follows:

1. Based on the numerical analysis of three pattern block parameters, it can be concluded that the ground pressure of the pattern block changes greatly when the transverse groove angle changes. With the increase of the transverse groove wall angle, the grounding pressure distribution of the pattern block becomes more uniform, and the wear resistance is improved simultaneously.
2. By analyzing the effect of the transverse groove angle on pattern stiffness, it is found that the longitudinal stiffness varies greatly when the transverse groove angle changes. The longitudinal stiffness increases with the increase of the transverse groove angle. Therefore, it is concluded that the change of the longitudinal stiffness of the pattern block has the greatest influence on its wear resistance. In the design of tire pattern, the longitudinal stiffness of the pattern can be appropriately increased to improve the wear resistance of the tire.

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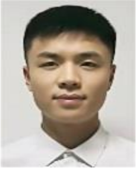

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