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Bionic Wear Resistant Design of Tire Tread Block Surface Shape

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***Abstract* – In order to improve the wear resistance of complex pattern tire, the bionic design of tread pattern block was carried out on the 205/55R16 radial tire for passenger car. Firstly, the finite element model of tire with bionic pit structure on the surface of tread block was established, and the friction energy loss rate was selected as the evaluation index of tire wear resistance. The experimental scheme was designed by orthogonal experiment to study the influence of surface morphological parameters (pit diameter, pit depth and pit center distance) of bionic non-smooth pits on the friction energy loss rate. The results show that the pit diameter has the greatest effect on the friction energy loss rate, followed by pit depth, and pit center spacing has the least effect on the results. The friction energy loss rate of the bionic concave pattern tire designed according to the bionic principle is lower than that of the smooth pattern tire, which can improve the wear resistance of the tire.**

***Keywords* –Tirepattern, Bionics Design, Tire Wear, FEM.**

I. INTRODUCTION

Tire bionics is to apply biological advantages to tire structure design in the process of tire design to improve tire performance. At present, tire bionics research has become one of the hot spots in the industry [1]. In biological evolution, the body surface morphology of many organisms has gradually changed, and the body surface has formed non-smooth structures. These structures often have the functions of reducing viscosity, resistance and wear resistance, so as to improve the anti-friction ability of the body surface [2]. For example, pangolins, lizards and shells, which shuttle in sand or soil for a long time, often have friction on their body surface but are not damaged, indicating that the non-smooth shape of their body surface has good wear resistance. Therefore, by observing the surface morphology of these organisms, it can be found that the common feature of these surface morphology is that they all have pit micro units.

In addition, scholars have done a lot of research on bionic tires and non-smooth pits. Hantai company designs tire patterns based on the shape of polar bear toes, which improves the adhesion of tires on ice and snow roads [3]. Zhou Likun and others studied the adsorption of Octopus suction cups, and applied its structural characteristics to tire design to improve the anti-skid performance of tires on ice and snow roads [4]. Fu Jing and others analyzed the characteristics of the flexible structure of kangaroo toes and found that its structure has the effect of slowing down the impact. They applied it to the design of pattern groove wall. Through simulation, it was found that the bionic pattern structure can effectively improve the grip performance [5]. Mao et al. Took the honeycomb structure as the bionic prototype, through the analysis of the honeycomb structure and arrangement, combined with the characteristics of automotive rubber materials, designed a composite bionic tread rubber with high wear resistance and wet skid resistance [6]. At present, bionic pit structure has been applied in different fields by many scholars, trying to improve the wear resistance of different products. Yang zhuoju an applied the pit type non-smooth structure to the surface of 55 steel roll, and studied the influence of temperature, pit size and other influencing factors on the wear resistance of the sample. Comparing the bionic non-smooth roll with the smooth surface sample, it is found that the non-smooth roll with pits on the surface has better wear resistance [7]. Sohyun studied the erosion problem of mechanical parts, prepared bionic samples with V-shaped grooves according to the biological surface morphology, and studied the erosion resistance rate of bionic samples with V-shaped groove structure under different impact angles, providing a reference for artificial erosion resistant surface design [8]. Biermann W. et al. Transferred the honeycomb surface structure and the optimized concave structure of the beetle head to HSS steel, focusing on the impact of surface structure on friction and wear behavior [9]. Liang Yingna et al. Applied the pit shaped bionic non-smooth structure to the surface of the slipper pair and found that the bionic pit made the lubricating film have a certain bearing capacity [10].

Therefore, based on the above research, the non-smooth pit structure is taken as the research object, and the pit diameter, pit depth and pit center spacing are selected as structural parameters for the surface design of 205/55R16 passenger car radial tire pattern. Taking the friction energy loss rate as the evaluation index, the wear performance of bionic tire with non-smooth pit structure is analyzed by finite element method, and the structural parameters are optimized in order to improve the wear performance of tire pattern.

II. Establishment of Finite Element Model

A. *Constitutive model of rubber*

The tread block finite element model built in this paper uses 205/55R16 radial tire tread rubber. Because the material composition of tire rubber is complex and has a variety of nonlinear mechanical characteristics [11]. Therefore, Yeoh material constitutive model with low requirements for the total amount of test data but good fitting accuracy is selected for simulation [12], it is strain energy density function is: $W = C_{10}(I_1 - 3) + C_{20}(I_1 - 3)^2 + C_{30}(I_1 - 3)^3$.

Where, W is the strain energy density of the material; C_{10}, C_{20} and C_{30} are deformation tensors; I_1 is the first fundamental invariant of material. In order to obtain the corresponding parameters of Yeoh model, uniaxial tensile test was carried out on the tread to obtain its material data. The test equipment is GOTECH AI-7000M electronic tensile testing machine, which is tested by referring to the national standard GB/T 528-2009 [13]. The test ambient temperature is standard room temperature, the tensile rate is 1%/s, and the strain magnitude is 100%. In order to ensure the reliability of tensile data, each rubber sample to be tested needs to be tested repeatedly, and the average tensile value is taken. The tensile specimen adopts the national standard I dumbbell type, and its shape and specific size are shown in Figure 1.

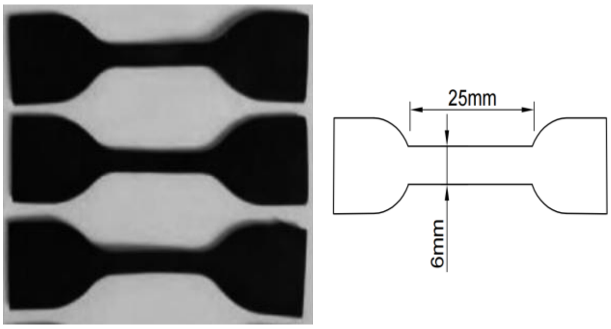

Fig. 1. Rubber tensile samples and dimensions.

Through the fitting toolbox of ABAQUS, the mechanical data obtained from the test are fitted, and the relevant parameters of Yeoh model are obtained. The fitting curve is shown in Figure 2.

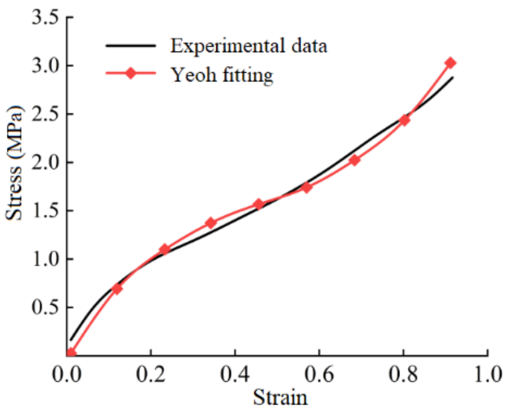

Fig. 2. Yeoh model fitting curve.

B. *Finite Element Model of Bionic Tread Tire*

Considering the operability of actual production and processing technology, the size and distribution of pits are taken. The shape of pits is shown in Figure 3. Take the pit diameter d as 2 ± 0.2mm, the pit depth h as 0.12 ± 0.02mm, and the center spacing w of pits as 6 ± 0.2mm [14]. Figure 4 shows the geometric model of the pattern block with bionic pit surface, and the size of the pattern block is 26×26×7mm. In order to simplify the calculation, the pits are distributed in parallel. In order to simplify the calculation, the pits are distributed in parallel.

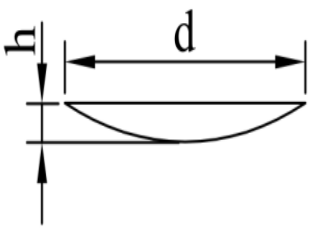

Fig. 3. Shapes of the pits.

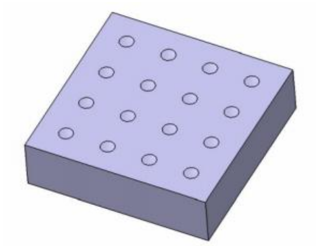

Fig. 4. Geometric model of bionic pitted pattern block.

The pattern model needs to be established separately. First, a single pitch pattern three-dimensional model is established, and then it is meshed. In the finite element software, the pattern block model is bound with the tire matrix model, and the three-dimensional model of the tire with complex single pitch pattern is rotated to form a complete three-dimensional model. The three-dimensional model of bionic dimpled tire is shown in Figure 5.

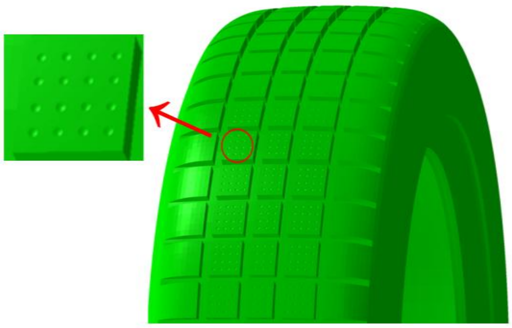

Fig. 5. Three-dimensional model of bionic pitted tire.

After the completion of tire mesh generation and material assignment, the pavement is defined as an analytical rigid body, and then the tread pavement contact pair is defined. Then apply upward concentrated load to the pavement to simulate the static loading process. Finally, set a certain moving speed and rotating angular speed for the tire.

III. Wear Performance Evaluation Index

Tire wear is mainly caused by the friction and slip between the tire and the ground. Rubber materials produce a lot of energy loss when they are deformed, especially when they slip under braking conditions. Therefore, the wear performance can be characterized by the energy loss when the tire slips. The energy loss rate of sliding friction can be expressed by the product of shear force and sliding speed, and its formula is as follows:

$$E = F_S \cdot v \tag{1}$$

Where, F_S is shear force and v is slip velocity.

In the contact area between the tire and the road surface, each contact unit (i, j) will generate contact pressure. When the tire moves, each contact unit will generate shear force $f_s(i, j)$. At the same time, slip speed will be generated $v(i, j)$. From formula (1), the friction energy loss rate of each contact unit $E(i, j)$ is:

$$E(i, j) = f_s(i, j) \cdot v(i, j) \tag{2}$$

Where: $f_s(i, j) = P(i, j) \cdot A(i, j) \cdot \mu(i, j)$.$A(i,j)$ is the area of contact unit, $\mu(i, j)$ is the friction coefficient. The area of the contact unit $A(i, j)$ can be expressed as:

$$A(i, j) = \frac{S}{n} \tag{3}$$

Where, $S$is the total grounding area and$n$is the number of contact units.

Then the total friction energy loss rate when the tire slips is:

$$E = \sum_{i=1}^{n}\sum_{j=1}^{n} E(i, j) = \frac{\mu S}{n}\sum_{i=1}^{n}\sum_{j=1}^{n}[P(i, j) \cdot v(i, j)] \tag{4}$$

By calculating the friction energy loss rate, the instantaneous wear of the tire contact area can be obtained more accurately. Therefore, the friction energy loss rate is used to characterize the wear performance of tires.

IV. Experimental Design

The effect of bionic non-smooth pit surface on the wear performance of pattern block is studied through experimental design, and the friction energy loss rate is taken as the evaluation index. Take the surface morphology parameters (pit diameter, pit depth and pit center spacing) of the pit as the influencing factors, and the factor level table is shown in Table 1.

Table 1. Factor level table.

Level	Factor			
	Pit Diameter A	Pit Depth B	Center Spacing of Pits C	D (Empty Column)
1	1.80	0.10	5.80	0.00

Level	Factor			
	Pit Diameter A	Pit Depth B	Center Spacing of Pits C	D (Empty Column)
2	2.00	0.12	6.00	0.00
3	2.20	0.14	6.20	0.00

Orthogonal experiment is another design method to study multi factors and multi levels. It is an efficient, fast and economic experimental design method. This test is a 3-factor and 3-level test, so $L_9(3^4)$ is selected. Interaction is not considered in the test. The test scheme is shown in Table 2.

Table 2. Experimental Scheme.

Test Serial Number	Factor Code			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

V. Result Analysis

According to the test design in Table 2, each group of schemes is simulated under standard working conditions. The calculation results of friction energy loss rate of each scheme are shown in Table 3. Test No. 0 represents the original scheme (smooth surface pattern block).

Table 3. The experimental results.

Test Serial Number	Pit Diameter A	Pit Depth B	Center Spacing of Pits C	Friction Energy Loss Rate (J/s)
0	0	0	0	10256.52
1	1	1	1	10175.16
2	1	2	2	10185.89
3	1	3	3	10196.41
4	2	1	2	10130.22
5	2	2	3	10172.81
6	2	3	1	10194.52
7	3	1	3	10079.13
8	3	2	1	10120.61

Test Serial Number	Pit Diameter A	Pit Depth B	Center Spacing of Pits C	Friction Energy Loss Rate (J/s)
9	3	3	2	10119.24

It can be seen from the above table that the friction energy loss rate of the nine groups of test schemes with bionic pits is lower than that of the original scheme, of which the friction energy loss rate of scheme 7 is the smallest, that is, A3B1C3, with a pit diameter of 2.2mm, a pit depth of 0.1mm, and a pit center spacing of 6.2mm.

In order to study the influence of the three morphological parameters of the pit on the tire friction energy loss rate, the range analysis is carried out on the test results in Table 3, and the range analysis results are shown in Table 4.

Table 4. Range analysis results.

	Pit diameter A	Pit depth B	Center spacing of pits C
K_1	30557.46	30384.51	30490.29
K_2	30497.55	30479.31	30435.35
K_3	30318.98	30510.17	30448.35
$\overline{K}_1$ $\overline{K}_2$ $\overline{K}_3$	10185.82	10128.17	10163.43
$\overline{K}_2$	10168.85	10159.77	10145.12
$\overline{K}_3$	10106.33	10170.06	10149.45
R	79.49	41.89	18.31

According to the range analysis results in Table 4, the factor that has the greatest impact on the friction energy loss rate is the pit diameter, followed by the pit depth, and the pit center spacing has the least impact on the results. The horizontal effect diagram of each factor is shown in Figure 6.

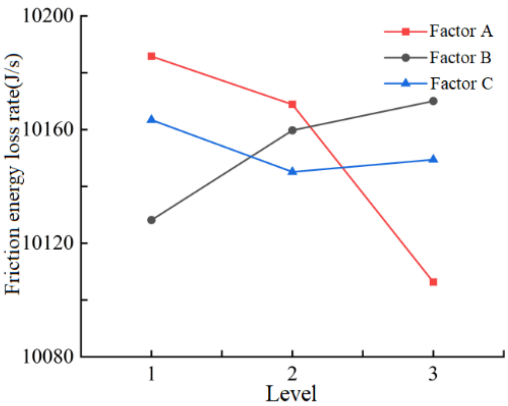

Fig. 6. Horizontal effect of factors.

It can be seen from the figure that the preferred factor level for reducing the friction energy loss rate is A3B1C2, that is, the pit diameter is 2.2mm, the pit depth is 0.1mm, and the center spacing of pits is 6.0mm.

Apply the optimization scheme obtained from the above tests to the surface design of the tread block, establish a whole tire model for simulation, calculate its friction energy loss rate, and compare it with the smooth square tread tire. The simulation results are shown in Table 5.

Table 5. Comparison of simulation results.

	Original Scheme	Bionic Scheme	Optimization Rate
Friction energy loss rate(J/s)	10256.52	9894.65	3.53%

The diameter of the surface pit of the bionic non-smooth structure is reduced due to deformation, and the volume of the pit is reduced, so that the air in the pit has a pressure effect opposite to the working pressure on the paired work piece surface, which reduces the pressure on the friction surface and is conducive to improving the stress distribution of the friction surface. When two work pieces rub, the generated debris is stored in the pits of the non-smooth surface structure, which can avoid the damage to the friction surface. Moreover, according to the simulation results in the table, the friction energy loss rate of the bionic dimpled tire designed according to the bionic principle is lower than that of the smooth tread tire, which has the effect of improving the wear resistance of the tire.

VI. Conclusion

By observing the morphology of the biological surface with good wear resistance, it is found that the non-smooth morphology of the body surface has pit micro units. Taking this as the research object, a tire finite element model with bionic non-smooth pit structure is established. Taking the friction energy loss rate as the evaluation index, the influence of bionic non-smooth pit structure parameters on the wear resistance of tires was studied through orthogonal experimental design. The conclusions are as follows:

(1) The bionic wear-resistant pit structure is applied to the surface shape design of tire pattern blocks, it can effectively reduce the tire friction energy loss rate. Compared with the original tire, the optimization rate of bionic tire is 3.53%, which improves the wear resistance of tire.

(2) Through the range analysis of the three morphological parameters of the bionic pit structure, it is found that the biggest influence on the friction energy loss rate is the pit diameter, followed by the pit depth, and the center distance of the pit has the smallest influence on the result.

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