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Tire Crown Wear Research and Finite Element Analysis

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***Abstract* – Wear performance is the key performance to measure the service life of the tire, and the tire crown is the most severely worn part of the tire. The 205/55R16 longitudinal groove radial tire was simulated and studied, and the driving conditions of the vehicle under different working conditions were simulated and analyzed with the frictional energy loss rate and ground pressure deflection value as the evaluation indicators. Through modeling analysis, the influence of different tire pressures and loads on tire wear was studied. The wear conditions under different slip angles are analyzed, and the results show that the ground contact pressure of the tires is unevenly distributed under the side slip angles of 2°, 4°, and 6°, which will cause uneven tire wear.**

***Keywords* – Tire, Wear Characteristics, Finite Element Analysis.**

I. Introduction

With the development of modern society, people's demand for vehicles in various complex working conditions is increasing day by day, and in-depth research has been carried out on the wear performance of tires. In the field of wear, through the efforts of scholars at home and abroad, it has been perfected; the research methods include finite element method, unit wear mileage method, tire wear energy method and so on.

Cho J.C et al. used the finite element method and the weighted coefficient method to divide the tire road wear test into 45 different working states, and established a dynamic simulation model of the tire based on the secondary development of Abaqus, and obtained a comparison with the test. The results are consistent with the conclusion. Fleischer believes that "when the frictional energy stored in a local volume reaches a critical value sufficient to destroy the surface, the local volume will break away from the surface in the form of wear debris". And generally ground friction is the research object. P.R. STUPAK, J.A. DONOVAN believed that wear phenomena include tensile, fatigue, mechano chemical, thermo chemical and oxidative processes. When calculating the tire wear amount, Zheng D et al. used the weight coefficient (the proportion of each state in the tire life), divided the entire running process of the car into 9 different situations, and carried out simulation analysis to obtain the friction energy loss rate under different conditions is obtained, and finally the total calculation result is obtained by methods such as weighted summation. Hu Jingwen combined finite element and theoretical calculation, used adaptive mesh technology and Abaqus explicit processing technology to predict the tire tread wear performance, and further studied the tire wear resistance on this basis. Referring to the friction coefficient of Zheng D et al., Li Hongyu took the wear depth as the evaluation index, and then used the particle swarm optimization algorithm to analyze the wear of the test tire, and obtained the best result of reducing the friction coefficient. He Tao used the finite element method to study the free rolling state and braking state of the 205/55R16 tire, obtained the large deformation of the wheel along the sliding direction, and analyzed the non-uniform wear characteristics of the tire.

In this paper, the 205/55R16 longitudinal groove radial tire is studied, and the friction energy loss rate and gr-

-ound contact pressure deflection value are used as evaluation indicators, and CAD, Hypermesh and Abaqus software are used to analyze the influence of different loads and tire pressures on tire wear, and the slip angle is analyzed. The tire wear is analyzed for cornering conditions of 2°, 4°, and 6°.

II. Establishment of Finite Element Model of Longitudinal Groove Tire

A. *Material Model*

The rubber material of each part of the tire is different, so the overall rubber of the tire cannot be set to the same type. It should be divided into different regions according to the differences in their composition. Define the tread and tread as all-rubber materials; Carcasses and band layers are referred to as rubber-cord composites. Properties of Rebar material model are shown in Table 1. On this basis, the corresponding finite element model is established to ensure the accuracy of the finite element simulation calculation. In the case of large deformation, the Yeoh model has good accuracy and stability, which can better reflect its mechanical properties, so the Yeoh model is selected for simulation in this paper. The elastic strain potential energy expression is:

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

C_{10}, C_{20}, C_{30} is the expansion coefficient of a third-order reduced polynomial; for strain energy; is the first invariant of the strain.

Table 1. Reinforcement material properties.

Rebar Material	Young's Modulus (GPa)	Poisson's Ratio (μ)	Density (kg/m³)	Cross Sectional Area (mm²)	Spacing of Stiffeners (mm)	Cord Angle (°)
Belt steel wire 1	105885	0.29	7800	0.30	1.2	66
Belt steel wire 2	105885	0.29	7800	0.30	1.2	114
Carcass cords	5253	0.31	1350	0.45	1.0	0
Crowned layer	4908	0.31	1150	0.30	0.9	90
Bead	176116	0.29	7800	0.62	0	90

B. *Finite Element Model*

When building a finite element model of a longitudinal groove tire, since the tire is a symmetrical structure, the 2D section of half of the tire is first drawn with AutoCAD, and then imported into Hyper Mesh for meshing. Finally, the ABAQUS is used to rotate the model around the central axis of the wheel to obtain a three-dimensional finite element model. Tire finite element modeling process is shown in Figure 1.

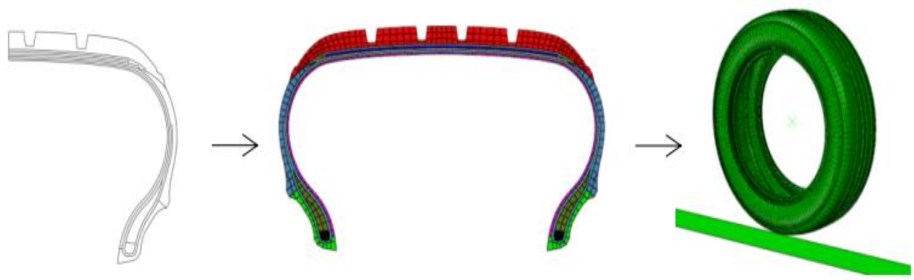


Fig. 1. Tire finite element modeling flow diagram.

C. *Model Validation*

The tire finite element model is tested and verified, and the static pressure test on the electronic universal test machine is used to obtain the ground mark and measure the sinking amount. We verify the model accuracy by comparing the obtained test data with the simulation results. At the tire inflation pressure was 250 kPa and the load was 4000N, the test pair of the tire radial stiffness and the simulation results, such as Fig. 2.It can be seen that the load-subsidence curves obtained from the test and the simulation are consistent, and basically coincide, and the relative deviation of the radial stiffness is also small .It can show that the built finite element model has high accuracy and can meet the simulation requirements.

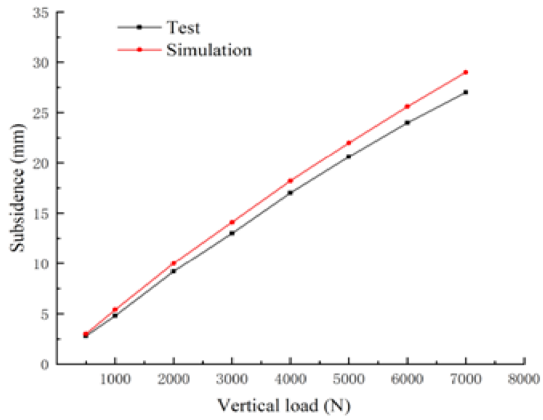


Fig. 2. Load-subsidence curve.

Grounding imprinting shape is an essential part of the tire analysis, it can reflect the tire grounding pressure distribution and other indicators. Taking the tire pressure of 250 kPa and the load of 4000 N as examples, the tire grounding blots of the test results and the simulation results are shown in Figure 3, and the grounding imprinted parameters are shown in Table 2.

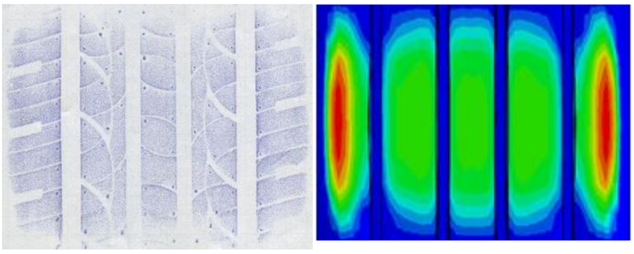


Fig. 3. Shape of grounding trace under static load.

Table 2. Grounding Trace Test and Simulation Value.

Ground Imprinting Parameters	**Test**	**Simulation**	**Relative Error /%**
The length of the long axis of the imprint /mm	140.09	143.57	2.5
Short axis length of imprinting /mm	100.10	102.60	2.5
Imprinting area /mm^2	14023	14730	5.0

III. Wear Calculation Method and Evaluation Under Complex Working Conditions

A. *Frictional Energy Loss Rate*

The frictional energy loss rate for any element is,

$$e(i, j) = f_s(i, j) \cdot v(i, j) = \mu(i, j) \cdot A(i, j) \cdot P(i, j) \tag{2}$$

Also denoted by $A(i, j)$ as the area of the unit,

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

S represents the ground contact area of the tire,

$$E = \sum_i \sum_j e(i, j) \tag{4}$$

Therefore, the total frictional energy loss is,

$$E = \frac{\mu S}{n} \sum_i \sum_j [p(i, j)] \cdot v \tag{5}$$

B. *Ground Pressure Deflection Value*

The ground contact pressure skewness value is a parameter used to evaluate whether the ground contact pressure distribution on the tire surface is uniform, and it is an important evaluation index for tire wear performance, its expression.

$$a = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (P_i - \bar{P})^2} \tag{6}$$

In the formula: P_i is the pressure of a certain node, n is the number of effective points, and $\bar{P}$ is the average distribution pressure. After exporting the finite element data, import the data in excel for unit conversion, and use the formula to obtain the ground pressure deflection value.

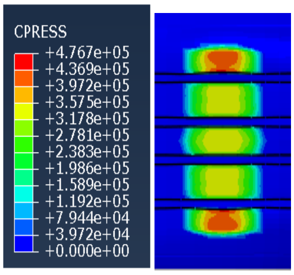
IV. The Effect of Load and Tire Pressure on Tire Wear

A. *The Effect of Different Loads on Tire Wear*

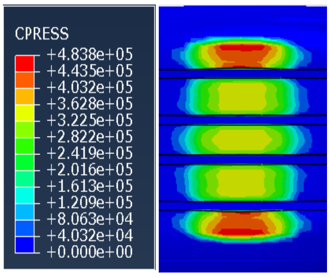
Load is an important parameter that affects the performance of tires during driving. In order to study the effect of load on tire wear, under the inflation pressure of 0.25MPa, five kinds of loads of 3000N, 3500N, 4000N, 4500N and 5000N were selected to design experimental schemes. As table 2. Figure 5 shows the distribution of ground contact pressure of tires under different loads.

Table 2. Design of different load schemes.

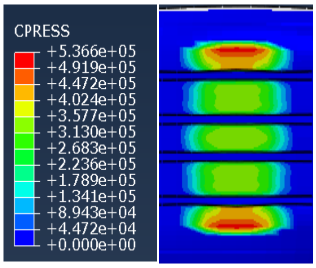
Loading Case	Load/N	Remark
1	3000	
2	3500	
3	4000	Rated load
4	4500	
5	5000	



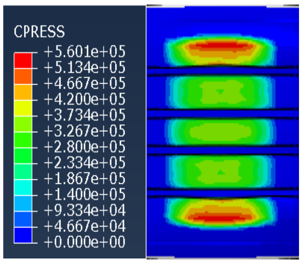
3000N



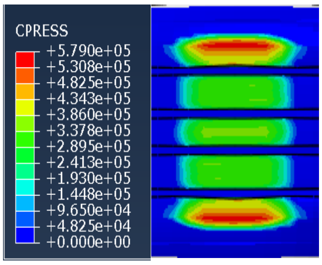
3500N



4000N



4500N



5000N

Fig. 5. Grounding pressure distribution of different loads.

Judging from the tire contact marks, as the tire load continues to increase, the pressure generated by contact with the road surface begins to continuously move to the shoulders on both sides of the tire. In the longitudinal direction, as the load increases, the ground contact area gradually extends longitudinally; in the transverse direction, it tends to expand to both sides. When the load is small, the tire contact marks are more evenly distributed between the tire and the road surface. When the load increases, most of the pressure is concentrated on the shoulders, which causes wear on the shoulders, reducing their service life.

Table 3. Simulation results of different loads.

Load Size/(N)	**Frictional Energy Loss Rate/(J/s)**	**Ground Pressure Deflection Value/(MPa)**	**Ground Area/(cm2)**
3000	7127.4927	0.1400	134.68
3500	8308.5912	0.1405	148.54
4000	9504.7614	0.1392	154.43
4500	10715.4462	0.1480	166.50
5000	11908.0060	0.1456	190.93

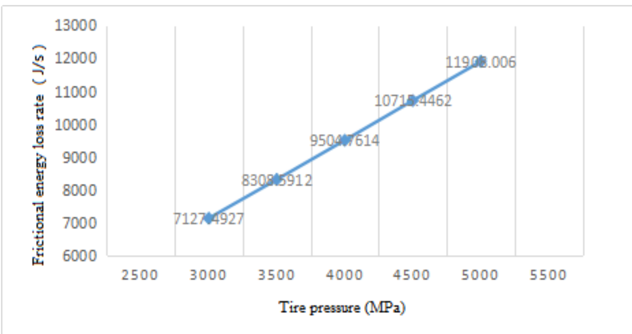


Fig. 6. Relationship between load and frictional energy loss rate.

It can be seen that under the condition of keeping the tire pressure unchanged, the size of the tire load and the frictional energy loss rate are roughly in a positive linear relationship. , the tire wear unevenness increases.

A. *Influence of Different Tire Pressures on Tire Wear*

Tire pressure is one of the most important factors in the driving process of a car. As the driving distance increases, the temperature of the tire rises, and the tire rubber will accelerate aging, resulting in cracks in the tread. In order to study the wear of tires under different inflation pressures, set the load to 4000N, and select five cases of inflation pressures: 0.17MPa, 0.19, 0.21MPa, 0.23MPa, 0.25MPa and 0.27MPa to design experiments, as shown in Table 4. Figure 7 shows the tire relay pressure distribution under different inflation pressures.

Table 4. Design of different tire pressure schemes.

Experimental Program	Tire Pressure/MPa	Remark
1	0.17	
2	0.19	
3	0.21	
4	0.23	
5	0.25	Standard tire pressure
6	0.27	

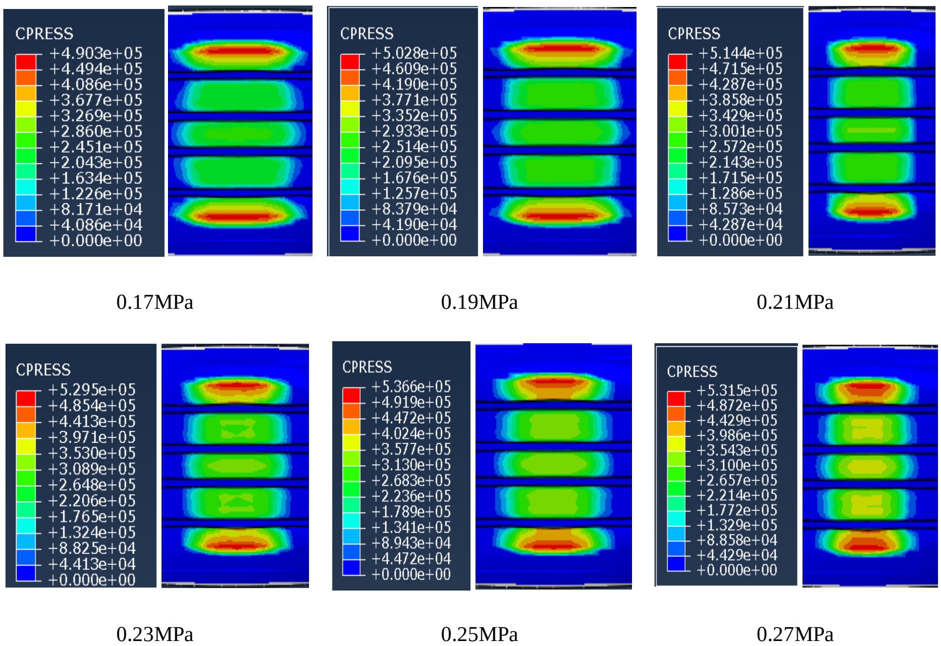


Fig. 7. Ground pressure distribution of different tire pressures.

It can be seen that when the load is constant, with the increase of tire air pressure, the pressure difference between the shoulder and the crown gradually decreases, while the center of the ground contact pressure tends to move from the shoulder to the center of the tread, and the wear increases. When the tire pressure is low, the ground pressure is relatively small, the stiffness of the tire is small, and the ability to resist tire deformation is also small, and the pressure is mostly concentrated on the shoulder of the tire; when the tire pressure is high, the stiffness of the tire is large, resisting the tire The ability to deform is also strong, and the center of ground pressure begins to shift from the shoulder to the center of the tread. Too high or too low tire pressure will cause uneven wear of tires and affect service life.

Table 5. Simulation results of different tire pressures.

Tire Pressure/(MPa)	Frictional Energy Loss Rate /(J/s)	Ground Pressure Deflection Value /(MPa)	Ground Area/(cm2)
0.17	9582.6825	0.1282	188.53
0.19	9544.6418	0.1355	187.94
0.21	9520.4892	0.1364	167.84
0.23	9515.2959	0.1345	153.90
0.25	9504.7621	0.1393	154.43
0.27	9493.6860	0.1477	154.88

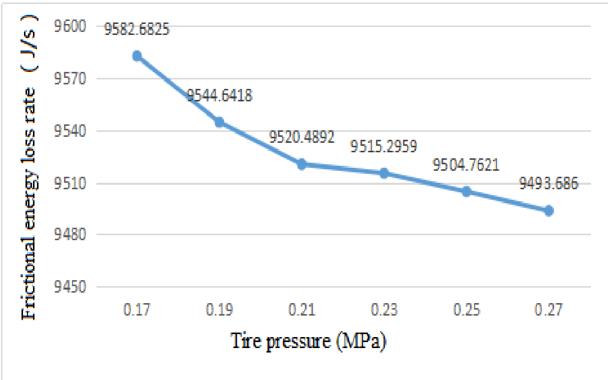


Fig. 8. Relationship between tire pressure and frictional energy loss rate.

From the data and change curve in the table, it can be seen that in the case of 0.21 MPa to 0.25 MPa, the change of the contact area and frictional energy loss rate is very small relative to its value itself, and the tire wear is caused by abnormal tire pressure. The effect of load is weaker than that caused by abnormal load, and the effect of load on tire wear is greater.

V. Wear Simulation Analysis Under Complex Working Conditions

Cars usually drive under many conditions, such as braking, yaw, roll, etc. In this paper, the braking and cornering conditions are simulated and compared with the free rolling conditions, and the corresponding conclusions are drawn.

A. *Wear Analysis of Brake Condition*

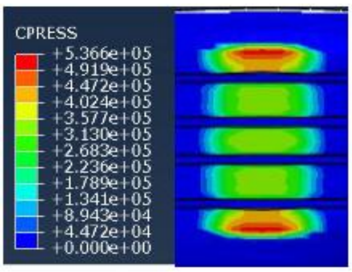


Fig. 9. Free rolling condition.

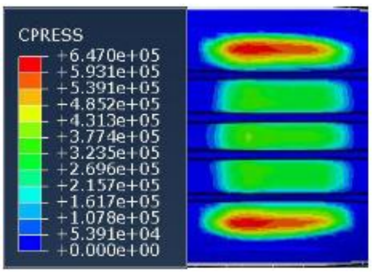


Fig. 10. Braking condition.

Table7. Analysis results of braking conditions.

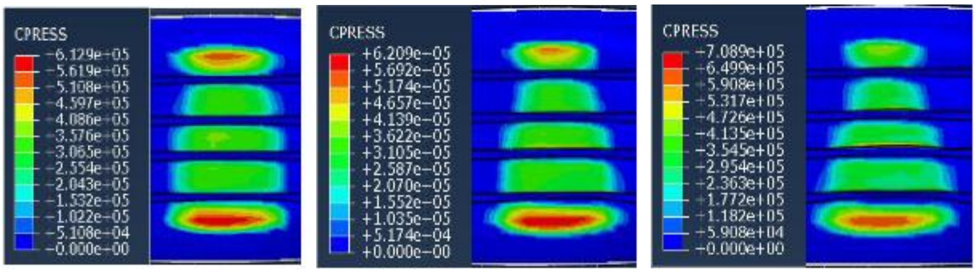
Braking condition	Frictional Energy Loss Rate/(J/s)	Ground Pressure Deflection Value/(MPa)	Ground Area/(cm2)
	13121.6388	0.153658	201.24

The grounding pressure distribution in the braking condition is similar to that in the free rolling condition. The grounding pressure on both sides of the tire shoulder is large, but the area with high grounding pressure at the shoulder tends to move backwards. The overall grounding pressure distribution is asymmetric about the horizontal axis. Ground pressure distribution is uneven. It shows that braking will affect the distribution of ground pressure between tires and road surface, resulting in uneven tire wear.

A. *Wear Analysis of Cornering Conditions*

Due to factors such as steering, road inclination, lateral wind, etc., the lateral force generated by the tire on the Y-axis is always directed towards the interior of the steering. Moreover, due to the lateral elasticity of the rubber tire, even if it cannot reach the limit of its adhesion, the direction of movement of the tire will be deviated, resulting in side deflection. Due to such cornering force, the tire develops a cornering angle determined by the angle between the longitudinal direction and the direction of travel of the tire.

The ground contact analysis is performed on rolling tires with slip angles of 2°, 4° and 6°, respectively, and the ground contact pressure distribution is shown in Figure 12.



Slip angle 2° Slip angle 4° Slip angle 6°

Fig. 12. Distribution of grounding pressure at different sideslip angles.

It can be seen from the grounding pressure distribution diagram that when the cornering angle is small, the grounding pressure distribution of the cornering condition is similar to that of the free rolling condition. But the difference is that when the cornering angle is too large, the grounding pressure center of the tire will shift to one side, that is, the force on one side shoulder will increase sharply, thereby increasing the friction loss of the tire shoulder part. When the slip angle increases, the overall shape of the ground contact pressure distribution develops from a rectangle to a trapezoid, and the shoulder wear increases while the shoulder wear decreases. The performance results are similar to the tire force condition of the car in the road environment with a roll angle.

Table 8. Simulation analysis results under lateral deflection conditions.

Angle/(°)	Cornering Force/(N)	Frictional Energy Loss Rate/(J/s)	Ground Pressure Skewness/(MPa)	Ground Area/ (cm2)
2	905.2	8548.3896	0.1413	153.88

Angle/(°)	Cornering Force/(N)	Frictional Energy Loss Rate/(J/s)	Ground Pressure Skewness/(MPa)	Ground Area/ (cm2)
4	1786	9553.9763	0.1436	149.09
6	2496	10654.6906	0.1459	138.21

After analysis, it can be concluded that with the increase of the side slip angle, the contact area between the tire and the ground decreases, the ground contact pressure skewness value increases, and the frictional energy loss rate also increases, which increases the uneven wear of the tire. The tire wear degree in the cornering state is greater than that in the free rolling state, and the uniformity of the ground contact pressure distribution is also poor.

VI. Conclusion

In this paper, the finite element model of tire is taken as the research object, the frictional energy loss rate and ground contact pressure skewness value are used as evaluation indicators, and CAD, Hypermesh and Abaqus software are used to discuss the influence of different loads and tire pressure on tire wear, and the impact on tire wear. The tire wear under different working conditions was analyzed.

1. By analyzing the effect of different loads and tire pressures on tire wear, and using them for wear calculation and simulation experiments, the effects of different tire pressures and loads on tire wear are obtained. It is concluded that when the tire pressure is constant, with the gradual increase of the load, the ground contact area continues to increase, and the ground contact pressure center shifts from the center of the tread to the shoulder area, resulting in abnormal wear of the shoulder area. When the tire pressure decreases, the tire will deform more, increase the ground contact area, and increase the wear. When the tire pressure is too high, the rigidity of the tire is larger, the ground contact area is reduced, the friction with the road surface will be reduced, the grip force will be reduced, and the wear of the middle part of the tire will increase, which will also cause uneven wear of the tire.
2. The side slip conditions with sideslip angles of 2°, 4° and 6° are simulated. The results show that, compared with the free rolling state, especially when the roll angle is 6 degrees, the shape of the contact patch under the cornering condition gradually changes from a normal rectangle to a trapezoid or even a triangle, which makes the shoulders of the tires on both sides of the tire change. The uneven wear intensifies, accelerating the overall wear of the tire and shortening the service life of the tire.

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