Finite Element Analysis of Stress Distribution Characteristics of Vehicle Retreaded Tire Composite Layer

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Abstract. In order to further reveal the failure and damage mechanism of retreaded tires in use, such as tread delamination and pressure burst, we constructed a retreaded tire material distribution model, a stress constraint model for each layer, and a finite element model. Stress distribution characteristics of the tread, breaker, belt, carcass, sidewall, toe rubber, etc. under free condition and static grounding condition were analyzed by numerical simulation, and the following main conclusions were obtained: Under the free-inflation condition, the tire carcass of the retreaded tire is subjected to the most stress, the belt is next to it, the breaker and the tread are the least, and the stress on the tread and tire shoulder is relatively great. Under the static grounding condition, the belt of the retreaded tire of a vehicle is subjected to the most stress, the carcass next to it, the stress distributions of the belt and the carcass are similar, and the stress on the tread and the breaker is relatively small.

1. Introduction
There are various methods for the disposal of used vehicle tires. In accordance with global development trends and environmental awareness, tire retreading has been promoted. Due to its unique low-carbon environmental protecting characteristic and advantages, it has developed rapidly in the vehicle tire industry and has accelerated the overall development of the tire industry [1]. Therefore, increasing the retread rate of used vehicle tires can effectively increase the utilization rate of used vehicle tires, which will greatly save rubber resources and promote environmental protection. In the process of using retreading tires, the tires often experience increased tread wear, chipping, delamination, and even failure modes such as pressing burst and puncturing burst. At present, researches mainly focus on improving the design of the tread rubber matrix formula and improving the retreading technology to solve the above problems, and the research on the comprehensive mechanical properties and internal micro-mechanical characteristics of retreaded tires of vehicles are few, resulting in uneven quality of retreaded tires and low service life [2-3]. To this end, by constructing a retreaded tire material distribution model, a stress constraint model for each layer, and a finite element analysis model, this paper qualitatively and quantitatively describes and evaluates the stress distribution characteristics of each layer of the retreaded tire, and further reveals the problems appearing when the retreaded tire are in use, such as tread delamination, pressing burst and other failure and damage mechanisms, so as to provide theoretical guidance for improving the performance of retreaded tires and optimizing the retreading technology.

2. Material Distribution Model of Retreaded Tire Composite Layer
This article takes 26.5R25 vehicle retreaded tire as the main research object, and its composite layer
material distribution model is shown in Figure 1. It is mainly composed of 7 parts: tread, breaker, breaker belt, old carcass, sidewall, toe rubber and bead ring [4-6].

![Material Distribution Model of Retreaded Vehicle Tires](image)

1. Tread 2. Breaker 3. Belt 4. Old Carcass 5. Sidewall 6. Bead Rubber 7. Bead Ring

Figure 1 Material Distribution Model of Retreaded Vehicle Tires

3. **Stress Constrained Models of Each Layer of Vehicle Retread Tires**

The strength and stiffness of the retreaded tires of a vehicle mainly depend on the maximum stress that various layers can withstand without being damaged due to external forces. Among them, the stress constraint model of the carcass layer of the retreaded tire [7-10] is

$$\sigma_t \leq \frac{10^3 P(R^2_k - R^2_0)}{2 R_k n i_k} \cdot K$$

(1)

where $\sigma_t$ — stress on the carcass, MPa; $P$ — tire pressure, kPa; $R_k$ — radius of the tread point, m; $R_0$ — radius of the widest point of the section, m; $n$ — wire of carcass layer-cord, layer; $i_k$ — wire of the tread point-cord density, piece/ m; $K$ — design safety factor of carcass.

The stress constrained model of belt [7-10] is

$$\sigma_d \leq \frac{10^3 P R_k}{n i_k \cos^2 \alpha_k} \cdot K$$

(2)

Where, $\sigma_d$ — stress of the belt, MPa; $P$ — inflated internal pressure, kPa; $R_k$ — crown point radius, m; $n$ — number of layers of wire ply working layers in the belt, layer; $i_k$ — density of the belt at the tread point, piece/ m; $\alpha_k$ — the wire on the belt-cord angle, (°); $K$ — design safety factor of the belt.

The constraint model of the stress on the tread, breaker and sidewall [7-10] is

$$\sigma_m \leq [\sigma_{mr}] \cdot K$$

(3)

$$\sigma_b \leq [\sigma_{br}] \cdot K$$

(4)

$$\sigma_s \leq [\sigma_{sr}] \cdot K$$

(5)

where $\sigma_m$ — stress on the tread, MPa; $\sigma_b$ — stress on the breaker, MPa; $\sigma_s$ — stress on the sidewall, MPa; $K$ — design safety factor of the tread, breaker, and sidewall; $[\sigma_{mr}]$ — maximum allowable stress on tread rubber material, MPa; $[\sigma_{br}]$ — maximum allowable stress on breaker rubber material, MPa; $[\sigma_{sr}]$ — maximum allowable stress on sidewall rubber material, MPa.

4. **Finite Element Analysis Model of Vehicle Retreading Tire**

The finite element model constructed by using ANSYS Workbench software is shown in Figure 2. The grid is divided into tetrahedral elements and some parts are refined. The model consists of 218,954 degrees of freedom, 79,478 nodes, and 32,666 elements. The material parameters of tread, breaker,
sidewall, toe rubber and bead ring are shown in Table 1. The material parameters of old carcass and belt are shown in Table 2. Among them, the tread, breaker, sidewall and toe rubber are simulated by Mooney-Rivlin model, the bead ring is simulated by Solid element, and the old carcass and breaker are simulated by Layer element [11-12].

Table 1. Material Parameters of Tread, etc.

| Material   | Elastic Modulus/MPa | Poisson's Ratio | Density/kg/m³ |
|------------|---------------------|-----------------|---------------|
| Tread      | 8.14                | 0.48            | 1810          |
| Breaker    | 6.12                | 0.48            | 1120          |
| Sidewall   | 9.96                | 0.48            | 1260          |
| Toe Rubber | 12.16               | 0.48            | 1470          |
| Bead Ring  | 2.11e5              | 0.29            | 7850          |

Table 2. Material Parameters of the Old Carcass and Belt

| Material   | Elastic Modulus/MPa | Shear Modulus/MPa | Poisson’s Ratio | Density/kg/m³ |
|------------|---------------------|-------------------|-----------------|---------------|
| Old carcass| 9.8e4               | 6.86              | 6.86            | 9.14          | 3.26          | 3.26          | 0.388 | 0.388 | 0.388 | 0.48 | 4650 |
| Belt       | 1.6e5               | 2.82              | 2.82            | 9.68          | 2.46          | 2.46          | 0.366 | 0.366 | 0.48 | 6570 |

5. Finite Element Analysis of Stress in Each Layer Under Free Inflation Condition

The comprehensive stress cloud diagram of the engineering retreaded tire at an inflation pressure of 600 kPa is shown in Figure 3. The maximum stress is 38.05 MPa, which occurs at the bead ring. The stress distribution along the radial direction of the tire is shown in Figure 4. From Figure 4, it can be seen that the stress on the carcass is the maximum, which is 0.81 MPa, followed by the breaker, which is 0.42 MPa, the stress decreases gradually along the breaker and the tread, and there is a large value at the shoulder of the carcass, which is 2.23 MPa. The results show that under the condition of free inflation of the retreaded tire of a vehicle, the main stressed component is the carcass, which expands outward under air pressure, which causes the belt, the breaker and the tread to expand outward and form a tight hoop. The effect indicates that the quality of the old carcass of used car retreaded tires will have a direct impact on the radial deformation of the free-inflated retreaded tires. The stress distribution curve of each layer along the tire width direction is shown in Figure 5. Among them, the carcass layer is subjected to the most stress, followed by the belt, the breaker, and the tread. The stress change law of each layer is basically the same. A larger value appears at the mid-line of the tread, but the carcass is different from other layers that the stress reaches a maximum at the shoulder. The results show that the shoulder of the old carcass of the retreaded vehicle must be carefully inspected before retreading. If there are damage defects, it will directly affect the mechanical properties of the retreaded tire.
6. Finite Element Analysis of Stress in Each Layer Under Static Ground Contact Condition

Figure 6 shows the comprehensive stress cloud diagram of the tire when the inflation pressure is 600kPa, the load is 135kN, and the interface friction coefficient is 0.9. As shown in Figure 6, the maximum stress is 15.11 MPa, which occurs at the belt.

The stress cloud diagram of each layer is shown in Figure 7, and the stress distribution curve of each layer along the tire width direction is shown in Figure 8. It can be seen from Figures 7 and 8 that the stress distribution in the tread ranges from 0.97 to 4.25 MPa, and the maximum stress value of 4.25
MPa occurs at the shoulder, gradually decreases toward the center of the ground contact along the width direction, and then becomes larger when approaching the center of the tread. The stress distribution range in the breaker is 0.49-1.65 MPa, the maximum stress value of 1.65 MPa occurs at the edge of the breaker, and the stress gradually decreases in the width direction toward the ground contact center. The stress distribution range in the belt is 3.40-14.90 MPa, the maximum stress value of 14.90 MPa appears at the center of the ground contact area between the belt and the breaker, and gradually decreases to the two sides along the width direction, and then increases at the edge of the belt. The stress distribution range in the carcass is 2.43-10.64 MPa, and its maximum stress value of 10.64 MPa appears in the center of the ground contact area between the carcass and the belt, and gradually decreases to the two sides along the width direction, and then increases at the edge of the carcass, which is similar to the changing trend of the belt. The stress distribution range in the sidewall is 1.45-6.38 MPa, and the maximum stress value of 6.38 MPa appears at the place where the sidewall contacts the shoulder. The stress distribution range in the toe is 1.45-9.58 MPa, its maximum stress value of 9.58 MPa appears inside the toe rubber.

(a) Tread Stress Cloud Diagram  (b) Breaker Stress Cloud Diagram  (c) Belt Stress Cloud Diagram
(d) Stress Cloud Map of Carcass  (e) Stress Cloud Map of Sidewall  (f) Stress Cloud Map of Toe Rubber

Figure 7 Stress Cloud Diagram of Each Layer

Figure 8 Stress Distribution Curve of Each Layer Along the Tire Width
7. Conclusion
(1) The composite layer material distribution model, stress constraint model of each layer, and infinite element analysis model of the vehicle retreaded tire were constructed, and the stress distribution characteristics of the vehicle retreaded tire were obtained.
(2) Under the condition of free inflation, the carcass of the retreaded tire is subjected to the most stress, followed by the belt, the stress on the breaker and the tread is smaller, and the stress on the shoulder is relatively large.
(3) The breaker belt of the retreaded tire of a vehicle is the most stressed, followed by the carcass, the stress distribution of the belt and the carcass is similar, and the stress on the tread and the breaker is relatively small.
(4) The results of finite element analysis show that the old carcass and belt of the retreaded tire of the vehicle are the main load-carrying components. Therefore, it is recommended that the quality inspection of the old carcass and belt should be strengthened before retreading, especially the quality of the bundle cord in the old carcass must be strictly tested.

Acknowledgments
Fund Project: Project supported by basic scientific research business expenses of Heilongjiang Provincial Undergraduate Universities (2018CX07); Heilongjiang Natural Science Foundation Project (LH2019E115); Heilongjiang Institute of Technology PhD Research Startup Fund Project (2016BJ02)
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Research interests: vehicle tire technology, vehicle driving safety.

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