Loading Deformation Characteristic Simulation Study of Engineering Vehicle Refurbished Tire

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Abstract. The paper constructed engineering vehicle refurbished tire computer geometry model, mechanics model, contact model, finite element analysis model, did simulation study on load-deformation property of engineering vehicle refurbished tire by comparing with that of the new and the same type tire, got load-deformation of engineering vehicle refurbished tire under the working condition of static state and ground contact. The analysis result shows that change rules of radial-direction deformation and side-direction deformation of engineering vehicle refurbished tire are close to that of the new tire, radial-direction and side-direction deformation value is a little less than that of the new tire. When air inflation pressure was certain, radial-direction deformation linear rule of engineer vehicle refurbished tire would increase with load adding, however, side-direction deformation showed linear change rule, when air inflation pressure was low; and it would show increase of non-linear change rule, when air inflation pressure was very high.

1. Introduction
For the past few years, with the rapid development of mining, building construction and so on, the demand for engineering vehicle tires is growing, the annual output of 2017 is about 11 million, which is about 0.5% of the total, but its sale accounts for about 6% of all tires. The amount used in an engineering vehicle tire is about 15% of the total amount of rubber, but its additional value is about 30% to 50% higher than that of other tires. Engineering vehicle tires are usually used in working areas in the open air, such as the soil or the stone pit mining area, which are large bearing, more frequent starting and braking, and the bump huge impact, thus the producing rate of scrap tires is faster and larger. Therefore, to increase the renovation rate of waste engineering vehicle tires can effectively improve the utilization rate of waste engineering vehicle tires, which saves rubber resource and promotes the green environmental protection. And engineering vehicle refurbished tire tread often occurs low wear resistance, easy to collapse cost block, and even appears loosing tread, and damaged forms by crushing and the blasting. At present, the research focuses mainly on the aspects of rubber modification enhancement technology and renovation process improvement. The study of the comprehensive mechanical properties of the engineering vehicle refurbished tire is relatively less, which leads to the poor performance of the engineering vehicle refurbished tire and the serious influence on the application of the such type of tire. Therefore, in this paper, by constructing computer geometry model, mechanical model, finite element analysis model of the engineering vehicle
refurbished tire, load-deformation of the engineering vehicle refurbished tire were qualitatively and quantitatively described and evaluated under the condition of static grounding condition, which provides theoretical guidance for the performance evaluation research.

2. Computer geometry model of engineering vehicle refurbished tire
This paper focuses on the 26.5 R25 engineering vehicle refurbished tires, whose constitute of the structure is shown in fig.1. It consists mainly of the tread layer, the buffer layer, the belt layer, the car-case layer, the side wall layer, the toe mouth rubber layer and the steel wire ring. The 3D assembly model of the static ground contact condition is shown in fig.2.

3 Ground contact model of engineering vehicle refurbished tire
The pair model of engineering vehicle refurbished tire contact with the ground was built using penalty function method, and described using the friction contact model, in the meantime, the tire tread was set up for the contact section, and ground as the target surface. Tread was both effected by normal force and tangential force, radial deformation of the refurbished tires was caused by the normal force, which could be described by formula (1), and the tangential force made the tread in sticking, or sliding condition, which could be described by formula (2).

\[ \begin{align*}
    f_n &= \begin{cases} 
    K_n C & (C \leq 0) \\
    0 & (C > 0) 
    \end{cases} \\
    f_s &= \begin{cases} 
    K_t \eta' & (\text{adhesive state}) \\
    \mu f_n & (\text{sliding state}) 
    \end{cases}
\end{align*} \]

In the formula, \( f_n \) —normal force, \( N \); \( f_s \) —tangential force, \( N \); \( K_n \) —normal contact stiffness, \( N/mm \); \( C \) —distance between tread and ground, \( mm \); \( K_t \) —tangential stiffness, \( N/mm \); \( \eta' \) —elastic deformation of the tread, \( mm \); \( \mu \) —sliding friction coefficient.

4 A finite element analysis model for engineering vehicle refurbished tire
The finite element analysis model is shown in fig.3 built in the ANSYS Workbench software, with a total of 35665 units, a total of 56655 nodes, and a total of 21988 freedom degree. Built pair model of
refurbished tire contact with the road surface is as shown in fig.4, in the case, the ground is the rigid target surface, refurbished tire is the flexible body contact surface, and the coefficient of contact friction between the two was set to 0.9.

Fig.3 Finite element analysis model
Fig.4 Contact pair model with ground

The tread layer, the buffer layer, the side wall layer, and the toe mouth the rubber layer applied the rubber Mooney-Rivlin model to simulate, the steel wire ring applied Solid unit to simulate, its material parameter is as shown in tab.1; The belt layer and the car-case layer used steel wire curtain line - rubber composite material Layer unit to simulate, thus the material parameters measured by the test are shown in tab.2.

Tab.1 Material parameters of tread layer and all layers

| Material                  | Modulus of elasticity MPa | Poisson's ratio | Density kg/m³ |
|---------------------------|----------------------------|-----------------|---------------|
| Tread layer               | 7.24                       | 0.48            | 1845          |
| Buffer layer              | 5.92                       | 0.48            | 1030          |
| Side wall layer           | 10.34                      | 0.48            | 1220          |
| Toe mouth rubber layer    | 12.12                      | 0.48            | 1380          |
| Steel wire ring           | 2.10 e5                    | 0.30            | 7800          |

Tab.2 Material parameters of car-case layer and belt layer

| Material      | Modulus of elasticity MPa | Shear modulus MPa | Poisson's ratio | Density kg/m³ |
|---------------|---------------------------|-------------------|-----------------|---------------|
| E₁            | E₂                         | E₃                |                 |               |
| Car-case layer| 9.8e4                      | 6.97              | 6.97            | 4602          |
| Belt layer    | 1.6e5                      | 2.60              | 2.60            | 6276          |

5 Finite element analysis results of engineering vehicle refurbished tire

The nephograms of integrated deformation, radial direction, and side direction of engineering vehicle refurbished tires are shown in fig.5 under the working condition of a 600kPa inflation pressure, 135kN load, and the 0.9 contact friction coefficient. Refurbished tire surface was flat and good contact with the ground, side tire layer was close to the ground layer and summoned up on both sides, moreover, the maximum radial deformation was 4.76 mm, and the maximum side deformation was 2.78 mm. The radial deformation and side deformation curves of engineering vehicle refurbished tire are as shown in fig.6 and fig.7, under the working condition of the inflation pressure is respectively 600kPa, 600kPa, 500kPa, 450kPa, load is respectively 135kN and 145kN, 155kN and 165kN, 175kN and 185kN, and contact friction coefficients is of 0.9.
6 Conclusion
The load-deformation feature computer geometry model, mechanical model, finite element analysis model of engineering vehicle refurbished tire were constructed under the condition of static grounding contact, the radial deformation and side deformation feature law of the engineering vehicle refurbished tire were obtained, and comparing analysis with the same model of new tires was carried out. Simulation results showed that the changing laws of radial deformation and side deformation of the engineering vehicle refurbished tire were close to that of the new tires, and deformation value was a little less than that of the same model and new tires. When inflation pressure was certain, with the increase of radial load, radial deformation increased and showed the linear rule, and the side deformation showed linearly increasing change law at the condition of low tire pressure increase, and non-linearly increasing change law at the condition of the high tire pressure, which indicates the aging degree of old tire body could produce a great influence on the deformation feature of engineering vehicle refurbished tire.

Acknowledgments
Project originating from: Heilongjiang Province Natural Science Fund in 2015(E2015025)

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