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Procedia Engineering 15 (2011) 5015 – 5019

Procedia Engineering

www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

FE simulation of tire wear with complicated tread pattern

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Abstract

A finite element tire with complex tread pattern instead of conventional smooth tread was modeled according to mathematic model based on Archard wear theory. For composite material such as ply and belt, a rebar layer model which is more accurate was introduced. Tire wear was simulated using ABAQUS code with programmed subroutine on the condition of straight free rolling, straight driving and straight braking. Wear depth and wear mass are introduced to assess the wear quantity.

Keywords: Ttire wear; Tread pattern; Finite element; Steady state rolling

1. Introduction

The economy of vehicle using shows its increasingly importance due to the non-renewability of energy. Reducing tire wear to prolong its service life and vehicle mileage has become an important issue that car maker and tire supplier have to face with. Finite element method is an efficient way to simulate tire wear. In recent years researchers have been studying on FE tires, but most of them were modeled as smooth tread or only keeping tread grooves. In this paper, a more complicated FE tire which takes tread pattern into consideration is modeled to study tire wear under different operation conditions.

2. Theory background

Researchers have developed different mathematical models for evaluating tire wear [1,2,3] , among —

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doi:10.1016/j.proeng.2011.08.932

which the adhesion wear theory introduced by Archard [4] in 1953 was widely adopted. Based on Archard wear theory the equation of tire wear on tread node was developed for finite element calculation.

2.1. Mathematic model

When two surfaces contacting, the actual contacts are the sum of areas of all the profile peaks. Archard wear theory assumes the profile peak of wear particle a hemispherical whose radius is equal to contact point. Contact area ΔA is [5,6]:

$$\Delta A = \pi \cdot a^2 \tag{1}$$

Where, a is wear particle radius. If contact causes plastic deformation, then:

$$\Delta A = \Delta F_N / H \tag{2}$$

Where, ΔF_N is Normal load at profile peak of contact point; H is Hardness of the softer material in contact pair.

If wear particle is proportional to the size of contact point, the volume of wear particle ΔV is:

$$\Delta V = \frac{2}{3}\pi \cdot a^3 \tag{3}$$

When slipping occurs between profile peaks of contact point the relative slipping distance at load ΔF_N is $\Delta L = 2a$.

For a pair of hemispherical wear particles the wear volume under unit slipping distance is:

$$\Delta W = \Delta V / \Delta L = \frac{1}{3}\pi a^2 = \frac{1}{3}\frac{\Delta F_N}{H} \tag{4}$$

Extending equation (4) to the entire contact surface the wear volume under unit slipping distance is obtained:

$$W = \sum_{i=1}^{n} \Delta W = K \frac{F_N}{3H} \tag{5}$$

Where, n represents the contact number on contact surface; K is wear factor.

The total wear volume V through slipping distance L is:

$$V = K \frac{F_N}{H} L \tag{6}$$

2.2. Equation for finite element calculation

Based on Archard wear model the equation for calculating wear of each node on tire tread can be developed. According to this equation finite element tire wear calculation was implemented with programmed subroutine in ABAQUS code.

Equation (6) can be expressed as:

$$V = K \frac{P \cdot A}{H} L \tag{7}$$

Where, P is the normal pressure on contact surface; A is contact area.

Slipping distance L is the product of slip rate $\dot{\gamma}$ and time t, the rate of wear volume then is:

$$\dot{V} = K \frac{PA}{H} \dot{\gamma} \tag{8}$$

$PA\dot{\gamma}$ represents, to a degree, the dissipation rate of friction energy between tire tread and ground. In this paper, wear factor $K = 10^{-3}$, material hardness H=2GPa. Tire tread can be regarded as the composition of stripes, which round tire in the peripheral direction. The center lines of these stripes are composed of finite element nodes, on which the pressure and slip rate are able to describe the features of surrounding area. Assuming that wear on each tire tread stripe is uniform, the rate of wear volume on each stripe can be derived:

$$\dot{V} = \frac{K}{H}\int_{ribbon} P(x,t)\dot{\gamma}(x,t)dA \tag{9}$$

Where, t is time variable; x is position variable. In this paper, steady-state transport code was used to calculate tire steady state movement, equation (9) is written as:

$$\dot{V} = \frac{K}{H}\int_{s} P(s)\dot{\gamma}(s)T(s)ds \tag{10}$$

Where, s is position variable along stripe center line; $T(s)$ is the stripe width at position s.
Creating $\dot{h}(s) = P(s)\dot{\gamma}(s)$, then:

$$\dot{V} = \frac{K}{H}\int_{s} \dot{h}(s)T(s)ds \tag{11}$$

Discretizing equation (8) and (11) simultaneously the uniform wear rate of tire tread $\dot{h}$ can be derived:

$$\dot{h} = \frac{K\sum_{i=1}^{N} P_i\dot{\gamma}_i\Delta s_i}{\sum_{i=1}^{N}\Delta s_i} \tag{12}$$

Where, N is the number of nodes on stripe center line. Equation (12) is the expression of wear on each tire tread node for finite element calculation.

3. Finite element model

The interaction between tire and the ground is implemented through the tread pattern. Different tread pattern will cause different pressure distribution and slipping distance on tire, so as to different friction work which will exert strong influence on tire wear. A more accurate finite element tire with complicated tread pattern was modeled instead of conventional simple one without pattern.

A 225/50R17 type steel-belted radial tire was modeled in this paper. Tread pattern is showed in Fig 1.

Fig. 1. Tread pattern sketch

The two dimension cross section of tire model was imported and meshed in ABAQUS. By means of rotating this two dimension model 6° on tire axis a three dimensional sector part of tire which called single unit model was created (Fig 2.). The tread pattern has uniform pitch distribution around tire tread and modeled with 6° central angle for one single pitch. The single unit FE tire model with tread pattern, showing in Fig 3, was created by assembling single unit tire with single pitch tread pattern using Tie constraining in ABAQUS. The entire tire FE model was created by duplicating 59 single unit models around tire axis meanwhile the ground was simulated by a rigid surface vertically below the tire (Fig 4).

Fig. 2. Single unit FE model (without tread pattern)

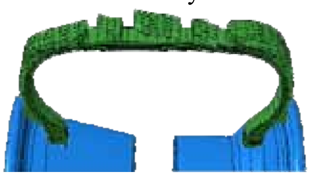

Fig. 3. Single unit FE model (with tread pattern)

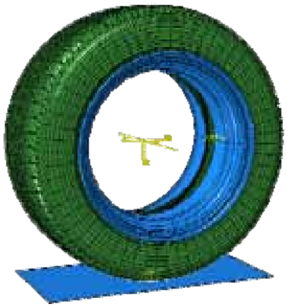

Fig. 4. Entire tire FE model (with tread pattern)

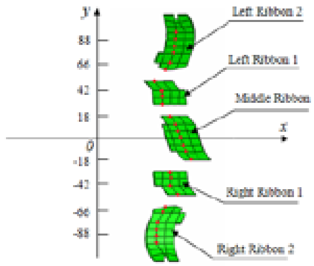

Fig 5. Position of nodes on single unit tread pattern

4. Tire wear simulation

Tire wear simulation was carried out using ABAQUS/Standard code with programmed subroutine. Wear depth and wear mass were introduced to describe the degree of wear according to equation (12). The nodes chosen to be calculated on the single unit transverse tread pattern is showed in Fig 5. Tire wear on the condition of straight free rolling, straight driving and straight braking was simulated.

4.1. Tire wear on straight free rolling condition

Rolling velocity was set to $V = 32km/h$, rolling angular velocity ω_f=31.656*rad/s.* The mileage was described by different increment steps *n* from 1 to 10. The relation between mileage and increment steps was: *mileage (km) = 3200×n.* Fig 6 shows the simulation result of wear depth with different increment steps. The maximum wear depth after 32000 km is 0.2mm, which indicates tiny degree of wear on the free rolling condition because of little slip rate. Meanwhile, the peak value of wear presents on the edge of each tread pattern. Wear mass, shows in Fig 7, increases uniformly with the increase of mileage.

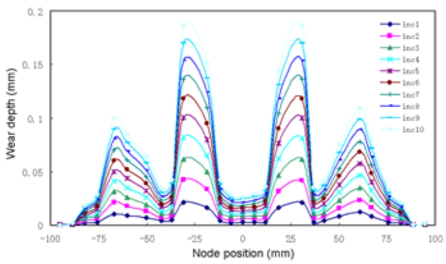

Fig 6. Wear depth of tread transverse (free rolling)

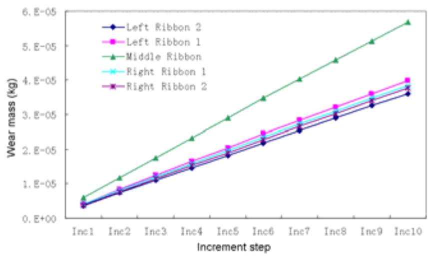

Fig 7. Wear mass of different tread pattern (free rolling)

4.2. Tire wear on straight braking condition

Rolling tire is on braking condition when the rolling angular velocity is set to *28.6rad/s*. The wear depth result in Fig 8 shows much severer wear than that on the free rolling condition duo to the higher *9.66%* slip rate. The peak value of wear depth which is more than *3.5mm* is located on the center of Left Ribbon 1 and Right Ribbon 1 after 32000km rolling. Wear mass in Fig 9 shows symmetrical wear on transverse of tread pattern and increases uniformly with the increase of mileage.

4.3. Tire wear on straight driving condition

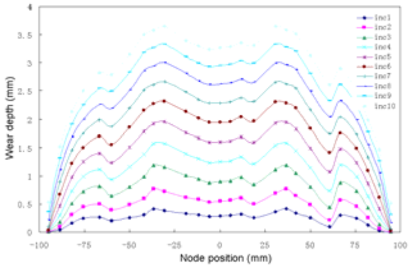

Fig 8. Wear depth of tread transverse (braking)

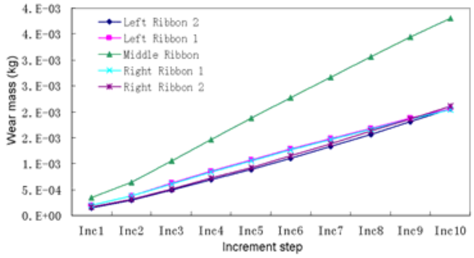

Fig 9. Wear mass of different tread pattern (braking)

Rolling tire is on driving condition when the rolling angular velocity is set to *34.6rad/s*. The wear depth and wear mass result (Fig 10 and Fig 11) after 32000km is similar to that on braking condition. Slip rate of tire on driving condition is *-9.66%* which is opposite in direction compared to that on braking condition.

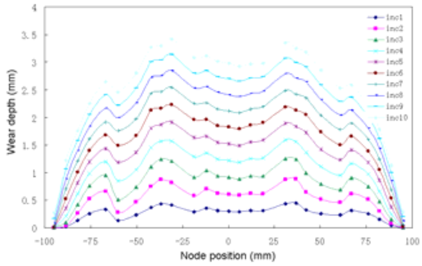

Fig 10. Wear depth of tread transverse (driving)

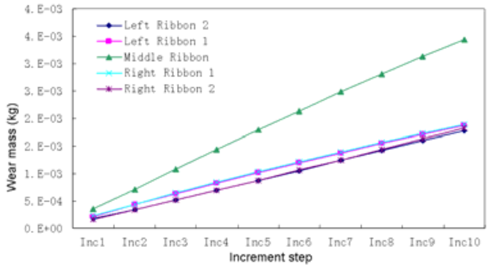

Fig 11. Wear mass of different tread pattern (driving)

5. Conclusions

A finite element tire with complex tread pattern was modeled to obtain more accurate tire wear simulation under different operation conditions. Tire wear was calculated using ABAQUS code based on Achard wear theory. Wear depth and wear mass are introduced to quantify tire wear.

On free rolling condition, there is tiny wear on tire due to little slip rate and increases linearly with the increase of mileage. Tread pattern has a large influence on wear distribution on tire transverse.

There shows much severer tire wear than that on the free rolling condition when tire is braking duo to higher slip rate. The wear distribution is symmetrical in the transverse direction of tread. Tire wear on driving condition has similar distribution feature to that on braking condition with only opposite slip direction.

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