Abstract

The process of curing a pneumatic tire as one of the most important working procedures, directly identify the quality of tire, because the physical and mechanical properties of rubber in the state of overcure or undercure are significantly decreased. The finite element analysis (FEA) method was introduced to evaluate the tire’s state of cure (SOC) in this paper, and the optimization of cure conditions of giant radial tire was also referred to ensure that tire constituents achieved the proper SOC and improved the quality of tire. Results indicated that when the cure time was cut down 35 minutes by optimization process, most part of tire compound is appropriate cured. So that the energy cost was remarkable cut down and the productivity was rising in evidence.

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1. Introduction

In condition of a certain pressure and temperature, the tire rubber crosslinking reaction occurs, and the using performance obtains. The physical and mechanical properties of rubber in state of overcure or undercure are significantly decreased. So ensuring that tire constituents achieved the proper state of cure (SOC) can improve the quality of tire. Giant radial tires are large, and the large difference is in the thickness, so the state of rubbers also have large difference and difficult to achieve the proper SOC. In order to overcome this obstacle, many researchers have done much great job. Browne and Wickkliffe[1] make much effort in the test of emission rate of the rubber, the natural convection between Rubber and air is discussed in detail and the method to identify the convection coefficient also is presented. These works
are very fundamental and necessary for FEA method. As the development of FEA method and computer technology, many complex problems can be solved by using FEA method. The vulcanization process just is a representative example of these.

This paper modeled the tire with aid FEA modelization, according to the actual tire vulcanization process, evaluated overall SOC of giant radial tire, which is agrees well with the experimental test. In order to reduce the difference of SOC of tire constituents, the curing time and curing temperature were changed. So that, the cure condition of giant radial tire was optimized.

2. FEA Model

2.1. 3D Model of Cure system

The cure system includes three parts, radial tire, cure bladder and mold part, which is shown at Figure 1(a). Giant radial tire 3D model was generated by revolving the axisymmetric model about its axis of revolution. In order to save computed time cost, the 40 degrees of 3D model was taken and divided into 20 portions.

Tread pattern was developed by CAD/CAE/CAM software UG. All the mesh of tread pattern is 4-node linear tetrahedron element created by ABAQUS/CAE. The assembly of tread pattern and other constitutes is shown in Figure 1(b).

2.2. Material property

In vulcanization process, density, specific heat, conductivity and convection coefficient all vary with temperature. So the temperature depended material properties are employed in this model to acquire correct results. ABAQUS offers very convenience way to defined properties that depend on temperature. Table 1 presents some of material properties which are used in this model.

Convection coefficient and emissivity are complex parameters which relate to material component participated, surface condition, shape and environmental conditions. Schlanger[2], Browne[1] discussed the measure method and range of convection coefficient in detail. According to the research of Browne, emissivity of rubber usually fluctuates around 0.94. The convection coefficient and emissivity was adopted form the literature[3]. The force convection coefficient is 1.5e-3, and the nature convection coefficient is 5.0e-6. The emissivity of rubber is 0.94.
### Table 1. Material property

| Material name     | specific heat (J/(kg*K)) | conductivity (10^4 J/(s*mm*K)) |
|-------------------|--------------------------|-------------------------------|
|                   | 40°C | 70°C | 100°C | 120°C | 40°C | 70°C | 100°C | 120°C |
| Under Tread       | 1657 | 1746 | 1994  | 2112  | 2.89 | 2.92 | 3.12  | 3.24  |
| Cap Tread         | 1417 | 1684 | 1931  | 2003  | 2.82 | 3.11 | 3.46  | 3.59  |
| Bead Filler       | 1587 | 1697 | 1925  | 2043  | 2.57 | 2.63 | 2.74  | 2.83  |
| Rim Cushion       | 1259 | 1579 | 1753  | 1964  | 2.4  | 2.5  | 2.7   | 2.88  |

### 3. Simulation of cure process

#### 3.1. Characterization of SOC

In practical application, the physical and mechanical properties of the melt is most cared, so the SOC also should be able to directly show the change trend of these properties. A new method named Departure of Torque (DOT) for quantifying SOC is presented. DOT comes from the rheometer torque, based on the rubber’s shear modulus of the variation to quantify the SOC, can accurately reflect the SOC of rubber component, and brings convenient to optimize the process conditions of vulcanization.

According to the definition of $M_{10}$ and $M_{90}$, which are shown at Figure 2. $M_n$ was defined as

$$M_n = M_L + (M_H - M_L) \times n\%$$  

(1)

Where $n$ is a number between 0 and 100; $M_L$ and $M_H$ is the lowest and highest Torque respectively in the cure process. The Torque is the function of curing time ($t'$), so we can express as

$$M_n = L(t')$$  

(2)

Take equation 4 into equation 3, $n$ also is the function of curing time ($t'$), which can be expressed as

$$n = L'(t')$$  

(3)

So we defined DOT ($S$) as

$$S = \begin{cases} 
  n - 100 & t_n < t_{100} \\
  100 - n & t_{100} \leq t_n 
\end{cases}$$  

(4)

When the value of DOT ($S$) less than -10, the crosslink reactions are not terminated; and when larger than 3, the polymer is over-cured; else the melt have good physical and mechanical properties.
In order to get the value of DOT, ABAQUS user subroutines UVARM is employed, which allows user to define output quantities that are functions of any of the available integration point quantities listed in the Output Variable Identifiers table[4].

3.2. Optimization of cure conditions

Fig. 3 (a) shows that most part of tire is over-cured, which is gray region. The color region is appropriate cured. There is uncured region occurs until curing time less than 7680 second (see in Fig.3(b)). However, the tread surface and inner surface also under over-curing state at the condition of 150℃. So the lower curing temperature is adopted, until the temperature is lower to 135℃, the over-cured area is largest and there is no under-cured area appears(see in Fig.3(c)).

4. Conclusions

Currently, the vulcanization conditions of giant engineering radial tire is difficult to determined, The shoulder always under-cured when sidewall is over-cured, due to the thick difference between them. Finite element method is very useful for optimizing the cure conditions of giant radial tire can be concluded from this paper. The establishment of optimize process based on the simulation results can be applied in actual manufactory process to provide the ruler and data for improving the curing conditions.

References

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