The energy saving research of the flat tire vulcanization process

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Abstract. Vulcanization was an important step in tire production process, directly determining the mechanical properties of the tire which was the most energy-intensive link. The traditional vulcanization process of a flat tire did not consider the post curing effect, which may result in a waste of energy. Early finite element simulation showed that the traditional process caused excessive vulcanization. In order to find ways to improve the curing process, in the paper effect of process parameters on the flat tire vulcanization had been studied. Curing parameters included heating temperature, curing time and preheating temperature. Corresponding to these three factors, the three-dimensional model was established by ABAQUS finite element software to carry out three groups of simulation. Result showed that heat source temperature on the maximum temperature was the largest, effect of preheating temperature was the lowest; heat source temperature on the curing degree was the largest, effect of the curing time was lowest. According to the data analysis the optimal process parameters had been raised.

1. Introduction

The developments of automobile industry put forward higher requirements for tire safety and comfort. The tire breakthrough was not only made in the structure design but also in tire curing process. The design of tire curing process could not stay in experience or half experience, but by simulating the actual vulcanization process and calculating vulcanization degree of rubber, the reasonable curing conditions would be determined to improve overall tire performance \cite{1}. Tire had complex structure and components, with various parts of different thickness, in curing process some parts would over cure and some parts would under cure. So understanding tire curing process had the vital significance for curing process optimization. By improving the structure, changing material and curing process, the best mechanical properties of tire were obtained with the lowest heat, so as to achieve the purpose of energy saving and low carbon. In the factory tire curing temperature was generally measured and curing degree was calculated. Compared with computer simulation, actual measurement method was time-consuming, and did not consider the influence of curing degree after vulcanization, conservative process would result in a waste of energy. Vulcanization was the most energy-intensive link in tire...
manufacturing. Through the computer finite element simulation, curing temperature and curing time were adjusted according to the simulation results, ultimately achieving the purpose of energy saving.

In this paper, with 255/30R22 tire as example, the finite element model was established by using the software of ABAQUS, the three groups of simulation was respectively carried, changing the heat source temperature, curing time and preheating temperature. Reaction heat was considered in three sets of simulations. Subroutine HETVAL was loaded by curing reaction heat. The temperature fields at sampling points were obtained. The subroutine UVARM was compiled to get curing degree field [2]. The establishment of finite element model, the simulation of temperature field and the calculation of vulcanization degree referred to articles [3-5].

In order to study the effect of sulfuration parameters on rubber vulcanization, the three comparison simulation had been designed. In the first group the vulcanization time was changed, set as 780 s, 720 s and 660 s. In the second group steam temperature was changed, set as 180℃, 170℃ and 170℃. In the third group preheating temperature or initial setting temperature was set as 150℃, 140℃ and 130℃.

2. The finite element simulation

2.1. The finite element model
Throughout the development of numerical simulation of tire curing it could be found that the heat transfer properties of anisotropic composite materials were not considered. In general, the mechanical properties of composites were anisotropic, and its thermal properties were also anisotropic [6]. The two-dimensional axisymmetric model and the three-dimensional model were as figure 1. In this thesis, curing temperature field and cure degree field of 255/30R22 tire had been researched. Figure 2 was sampling point diagram.

2.2. Vulcanization process
Although specific heat capacity and thermal conductivity of each rubber were similar, in order to ensure accuracy, change of thermal physical parameters with temperature was still considered [7]. According to the actual conditions of experiment, the initial temperature of the tire was set as 20℃, the initial temperatures of capsule and mold were 150℃. Vulcanization process was divided into five stages, continuing for 1540s. The boundary conditions of each phase were as follows:
The first phase was that the tire was in the mould. Upper hot plate and under hot plate were set as 180°C. This process lasted for 580s. The second stage was the tire was taken out from the mold. The entire tire was exposed to the air, the main way of heat dissipation was radiation and the radiation factor was 0.94.

3. Simulation results and analysis

3.1. The influence of curing time

Early by comparison of temperature simulation values and the measured temperature values at sampling points it showed that the simulation with reaction heat was accurate, simulation temperature curve and measured temperature curve were almost identical at each point. In this section the simulated values were no longer compared with the measured values. Figure 3 showed that temperature reduced by 5°C as the vulcanization time reduced by 60s. In the previous stage of vulcanization and after cure stage temperature curves were the same at each point, just the highest temperature and its corresponding time were changed. Cure degree of the triangle rubber was the highest. As vulcanization time reduced by 60 s, cure degree at each point reduced by 0.3. In figure 4, G curve was the optimal cure degree. By comparison the vulcanization time could be optimized for 600 s.

![Figure 3](image)

(a) 1 point  (b) 2 point  (c) 3 point

Figure 3. The temperature and vulcanization degree curves over time at the sampling points.

3.2. The influence of heat source temperature

Figure 4 showed that impact of the heat source change on initial curing was not obvious, it was because in the initial vulcanization stage the tire was heated by residual heat in the mould. The change of the heat source changed the highest temperature and leaded to curve translation. As heat source temperature reduced by 10°C, the highest temperature at the sampling point reduced by 7°C. The effect of heat source on the cure degree was larger than the effect of curing time. As the heat source temperature reduced by 10°C, vulcanization degree reduced by 1. Heat source temperature of the traditional process could be optimized for 170°C.

![Figure 4](image)

(a) 1 point  (b) 2 point  (c) 3 point

Figure 4. The temperature and vulcanization degree curves over time at the sampling points.
3.3. The influence of preheat temperature

Figure 5 showed that when preheat temperature reduced by 10°C, the temperature curve at each point only translated downward for a small distance. The impact of preheat temperature on the temperature curve was the weakest among three factors. But with time accumulated preheat temperature had large effect on cure degree, second only to the influence of the curing time. The optimal preheat temperature was 130°C.

![Temperature and Vulcanization Degree Curves](image)

**Figure 5.** The temperature and vulcanization degree curves over time at the sampling points.

4. Conclusions

Based on curing time, heat source temperature, preheating temperature, three groups of simulations had been carried out in the paper. The following conclusions could be drawn from temperature curves and cure degree curves:

- According to the influence on the highest temperature from high to low, factors were the heat source temperature, curing time, preheating temperature. According to the influence on vulcanization degree from high to low, factors were the heat source temperature, preheating temperature, curing time.
- The traditional crafts had optimizable space. By only adjusting the single factor, vulcanization time could be adjusted to the 600 s, heat source temperature could be adjusted to 170°C, preheating temperature could be adjusted to 130°C.

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