Numerical heat transfer study for a large rubber product

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ABSTRACT

The physical processes of heat transfer are typically complicated in the curing of rubber. In this study, the image plot and the plot of the temperature profile were obtained in such an environment, and then compared with the finite element method (FEM), which is used in finite element analysis (FEA) software. A good agreement was observed, and the difference was less than 1% when evaluating the different curing conditions. This confirms that the correct curing time can be determined by studying the temperature profile, which will help to avoid the deterioration of the mechanical properties of thick rubber products.

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1. Introduction

Engineering rubber products are widely used in many engineering sectors because of their excellent physical properties, such as the ability to deform strength, and their durability. The full range of engineering rubber products includes medical, aerospace, transportation, office automation, military and many other high technology applications [1]. Some of the rubber products are quite large in size due to the necessities of their applications, such as marine fenders, elastomeric bearings, shock cells for offshore application, or bulge tubes, using 200 tonnes of natural rubber as a wave energy converter [2], and many others.

Predicting the optimum curing time for large rubber products is a big challenge to the rubber industry, and merely implementing the Monsanto Oscillating Disc Rheometer has often proved to be insufficient to provide the correct curing time. The reason for this is that the data obtained from these curves relating to the processing physical and dynamic properties of rubber compounds are only valid for thin or small rubber products [3]. The main reason for this is the existence of temperature gradients for a significant portion of the curing time during the curing process of large rubber products. Thus, the curing conditions are non-isothermal and also non-uniform throughout the component. A method is therefore needed for measuring the amount of heat received at other points, especially at the navel (center, center point) of the large rubber products [4].

Numerical methods, such as the finite element method and the finite difference method, might offer the solution to how to quantify the amount of heat received at other points. Thus, the equivalent curing time at the platen temperature can be calculated for any point at which the temperature history is known. Both of these methods will be discussed in this paper.

2. Overview of the theory relevant to the present research

The heat transfer theory will be described first in Section 2.1. The heating and cooling processes will be elaborated later in Sections 2.2 and 2.3, respectively.

2.1. Heat transfer theory

Heat transfer is a useful tool for understanding the non-steady state system and non-equilibrium system, where thermodynamics is unable to provide sufficient answers. It is also used to extend thermodynamic analysis through studying of the modes of heat transfer and through development of relations to calculate heat transfer rates during the curing process. The subjects of thermodynamics and heat transfer are highly complementary. For many heat transfer problems, the first law of thermodynamics (the law of conservation of energy) provides a useful and essential tool in formulating the transient conduction equation [5].

For a closed system (a region of fixed mass), there is heat transfer through the boundaries and work done on or by the system. This leads to the following statement of the first law for a closed system, and its corresponding governing equation is given by:
all the areas. The temperatures at the right, left, top and bottom reach a steady-state condition during the curing process as the temperature gradient in these regions is obviously small and the temperatures are near to 200 °C. After that, the temperatures in these regions decrease to approximately 160 °C, after the cooling process has started. Again, the temperature at the centre keeps increasing, starting from the initial 50 °C up to a temperature of 172.08 °C during the cooling process, as rubber has a higher specific heat and is thus able to store heat.

7. Conclusions

In this project, a comparison is successfully carried out between a FDM written in Matlab R2010b and a FEA (Abaqus 6.8). A good agreement between the two was observed. However, this simple FDM was constructed based on some presumptions, approximation related numerical method and simplification. The results shown in this FDM, which was used in this application of Matlab R2010b, is agreeable with results obtained from Abaqus 6.8.

The finite difference implicit method can be employed as the numerical method in this algorithm to save computation time, as it allows a larger value of step time increment. Although the implicit method is unconditionally stable, there is an accuracy limit to the use of larger time steps. In this case, because inaccurate intermediate results are not an issue, implicit methods allow the use of larger time steps to generate steady-state results in an efficient manner. Thus, the desired steady-state value of temperature and its corresponding time can be obtained faster and more efficiently. Again, implementation of the implicit method will generate more complicated algorithms, as it needs the formation of matrix and inversing the matrix by using the Gauss–Seidel iteration method or some other methods.

The analysis of the full model can be reduced to a quarter model by introducing two symmetrical lines. Eq. (6) can be revised and reduced into a simpler form by introducing Neumann boundary condition.

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