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Effect of holding time on curing process of composites

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Abstract

According to the heat transfer law of composite laminates cured by autoclave, the finite element method is used to establish the physical model and finite element mathematical model of composite laminates in this paper. The effects of different holding time on the performance index (temperature, curing degree,etc.) of composites are numerically analyzed, and the optimal holding time is summarized. These results can provide a numerical basis for improving the temperature field in the curing process of resin matrix composites, and therefore improving the thermal curing quality of resin matrix composites.

Keywords

Laminate of composite, temperature field, curing process, holding time.

1. Introduction

The curing process of composites is very complex and contains a variety of chemical and physical reactions[1]. Such as the thermal stress inside the material, the porosity of the material itself, and the density of the composites will change when the temperature or the pressure rise of fall, resulting in changes in the properties of the material. These factors all can have a serious impact on the curing process of the composite[2]. Owing to these uncertain factors above, there are many problems in trying to obtain ideal experimental results when performing traditional curing experiments. For example, the entire curing experiment spends too much time, and there are many uncertain factors in the curing experiment, which leads to the inconsistency of the results of multiple experiments. Therefore, in the current research on the thermal curing process of composite materials, researchers at home and abroad tend to use the finite element analysis method for simulating the whole curing process of composite. With the rapid advancement of computers and the emergence of finite element methods, the finite element analysis of the composite patches can predict the entire thermal curing process by simulating the data close to the real situation. Compared to traditional curing experiments, the finite element analysis method is easier to operate and the variables are easier to control[3]. It can also reduce the time and the cost required for production. As long as the numerical analysis is performed before the experiment, repeatable and reliable results can be obtained. By fixing other factors in the experiment, it is possible to simulate the effects of factors such as curing pressure, holding time and holding temperature of the curing process on the curing quality of the composite. At the same time, in the stage of establishing the physical model, the properties of the material, the initial conditions, the geometry of the material, etc. can also be changed to study its influence on the curing process. Therefore, through the finite element analysis method, the research content and direction that can be carried out are numerous and have a wide range of research[4].

Chen et al. [5] used the finite element analysis method to solve the problem of three-dimensional steady-state numerical values of temperature and thermal stress in the curing process of resin matrix

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composites patch. The effects of different laminated design and holding time on the curing process of the patch were analyzed. Bao [6] et al. simulated the pressurization process of resin matrix composites in autoclave, and studied the calculation method of determining the pressurization timing. The calculation results were compared with the experimental data for 5405 bismaleimide resin and 5284 epoxy resin. Finally, this research indicates that the data about these two resins are basically the same. Liu[7] et al. considered that the resin matrix composites were prone to deformation when they were cured by autoclave. The curing process in the autoclave was simulated and the influence of the thickness variation on the curing process was studied. Liu[8]established a thermo-chemical coupling model by studying the influences of thermal effects and chemical shrinkage on the solidification deformation of composites. The main conditions that affect the deformation of composite laminates are: resin volume shrinkage, fiber volume fraction and so on. When repairing composite materials, the key to the repairing performance of the material is the control of the temperature field distribution of the patch during the thermal curing process.

Bogetti[9] et al. established the temperature field of composite materials under the influence of different factors. The two-dimensional finite element model was selected as the research object. The factors affecting the temperature field and the degree of cure were as follows: the physical shape of the laminate, the anisotropy of materials, mathematical models of heat conduction, thermal curing methods, etc. Twardowski[10] et al. used thick-section repaired sheets as the research object to analyze the problems that often occurred during the curing process. The conclusions were as follows: the anisotropy of the internal viscosity and the degree of cure of the composite laminates are due to the maldistribution of the temperature field. The temperature distribution is affected by the external heat source and heat conduction. During the curing process, the peak of the temperature moves from the surface position of the laminate to the center position and gradually reaches the maximum value; the curing reaction process is not affected by the initial curing value of the material.

There are many reasons that affect the temperature field distribution during the thermal curing of composite materials. The curing time is an important parameter in the thermosetting molding process of composite materials. The resin matrix composite requires a suitable curing time to ensure the complete curing of the resin. Incompletely cured laminates are prone to deformation, bending, and the like. Therefore, the analysis and study of the influence of holding time on the thermal curing process of resin matrix composites are of high research value.

2. Calculation model

2.1 Physical model

The design laminate model has a length, width and height of 200mm, 200mm and 20mm. The model can be simplified according to the boundary conditions and the symmetry of the geometry. A quarter of the laminate is used to establish a finite element analysis model. The model is shown in Figure 1. The material is a 3234/T300B resin matrix composite. The initial conditions are: the initial temperature is 30℃(303 K), and the degree of cure is calculated from 0. The autoclave heats the upper surface and the side surface of the laminate, and the lower surface is adiabatic.

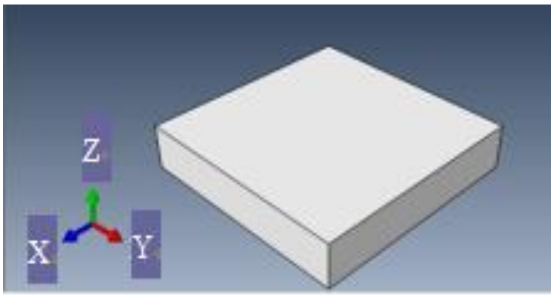

Fig. 1 The finite element model of laminate

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2.2 Transient heat conduction equation.

After selecting the origin of the coordinate, the longitudinal direction of the composite is the x-axis, the thickness direction is the y-axis, and the width direction is the z-axis. The principle of thermal equilibrium is applied to establish the heat-cured three-dimensional anisotropic transient heat conduction control equation of the resin matrix composite[11]:

$$k_{xx}\frac{\partial^2 T}{\partial x^2}+k_{yy}\frac{\partial^2 T}{\partial y^2}+k_{zz}\frac{\partial^2 T}{\partial z^2}+\dot{q}=\rho c_p\frac{\partial T}{\partial t} \tag{1}$$

In the equation: ρ indicates the material density, c_p indicates specific heat, T indicates temperature, t indicates time, and $\dot{q}$ is the heat generation rate of the curing reaction.

2.3 Initial conditions and boundary conditions of the curing process

Select a point in the laminate with the coordinates (x, y, z) and use this point as the research object. The initial conditions are[12]:

$$T(x,y,z,t)\big|_{t=0}=T_0,\alpha\big|_{t=0}=0 \tag{2}$$

$$T_t=T_s=T_H(t) \tag{3}$$

$$k_{zz}\frac{\partial T}{\partial z}\Big|_b=0 \tag{4}$$

In the equation, T_0 represents room temperature; α represents the degree of cure.

T_t represents the top temperature of the laminate;

T_s represents the side temperature of the laminate;

T_H represents the temperature at which the autoclave is heated;

T_b represents the laminate bottom layer temperature.

3. Calculation results and discussion

The curing temperature rise curve of the laminate is shown in Fig. 2. The autoclave temperature was heated from room temperature 303K to the set curing temperature 453K at a heating rate of 3K/min, and holding at 453K for 5200s, 7200s, 9200s, respectively, and then cooled to room temperature 303K at a cooling rate of 3K/min to complete the entire curing process. The time required for different holding times is 11200s, 13200s, and 15200s, respectively.

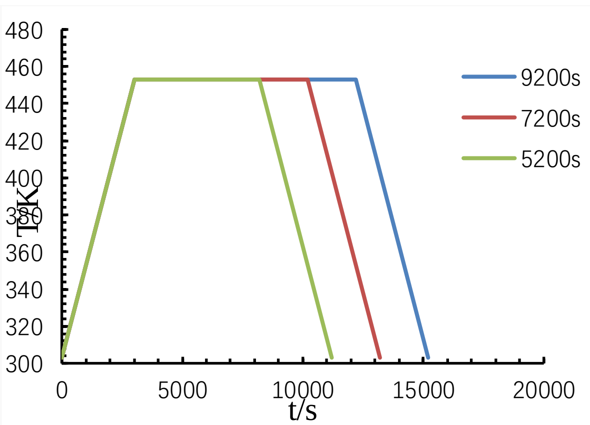

Fig. 2 Curing process temperature curve under different holding time

Figure 3 shows the temperature distribution inside the laminate at 11200 s which is the end of the thermal curing process with a holding time of 5200 s. The ambient temperature has just dropped to

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303K, so the top and side temperature of the laminate equal to 303K, but the internal temperature is still above ambient temperature. Since the lower surface is an adiabatic boundary condition, heat is transferd from the center of the bottom to the top and side, forming a temperature distribution as shown in Figure 3.

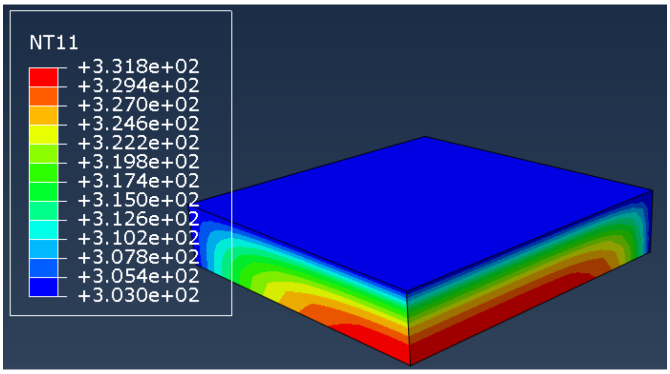

Fig. 3 Temperature field after cooling down with holding time of 5200s

Figure 4 shows the temperature distribution inside the laminate at 13200 s which is the end of the cooling in the thermal curing process with a holding time of 7200 s. Figure 5 shows the temperature distribution inside the laminate at 15200s which is the end of the heat curing process with a holding time of 9200 s. Comparing Fig. 3, Fig. 4 and Fig. 5, it can be seen that in the thermal curing process, under the same heating rate, holding temperature and the like, the temperature field of the repairing sheet has no significant difference under different holding time.

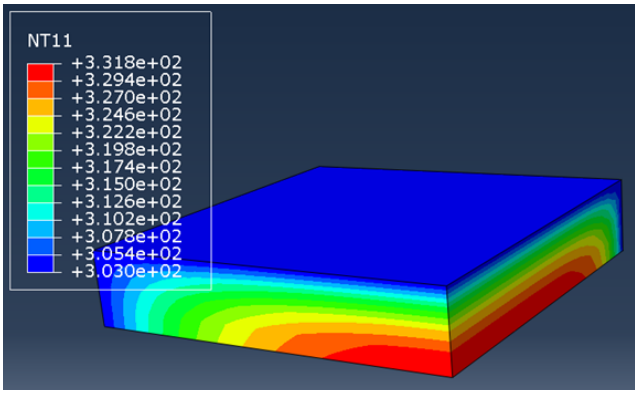

Fig. 4 Temperature field after cooling down with holding time of 7200s

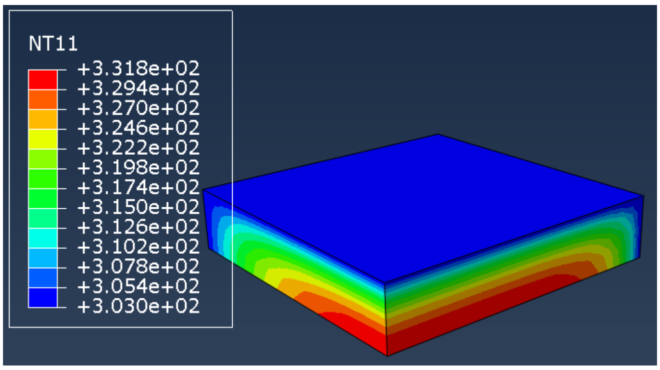

Fig. 5 Temperature field after cooling down with holding time of 9200s

According to cloud map above, the temperature gradient in the y direction (the thickness direction) of the laminate at the end of the cooling time can be calculated. As shown in Table 1, the temperature gradient is the same for different holding time conditions. While as the curing process proceeds, the temperature gradient decreases.

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Table.1 Temperature gradient at different holding times

Holding time(s)	5200s	7200s	9200s
Temperature gradient(K/mm)	0.688	0.688	0.688

4. Conclusion

(1) According to the heat transfer law of the curing of the composite in the autoclave, the physical model and finite element mathematical model of the 3234/T300B resin matrix composite were established.

(2) Numerical simulation of the temperature field during the curing process of laminates was carried, and the effects of holding time on the temperature field were studied. The results show that increasing the holding time can not improve the curing quality, instead leading to an increase in the time spent on the entire curing process.

Acknowledgements

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