The temperature field of the resin matrix composites patch of different thickness during curing process

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Abstract. The physical models of resin matrix composite material repairing for different thickness are established. Numerical simulation analysis is carried out for the temperature field of two kinds of patch thickness during the curing process by using the finite element method, and the internal temperature distribution of the thick composite patch and thin composite patch during the curing process are studied. The results show that: the temperature gradient of the thick section patches is larger than the thin section patch during heating stage and cooling stage in the curing process, and the temperature are the same during temperature maintaining stage for both patch thickness.

Keywords: temperature field, resin matrix composite, the curing process, composite patch, different thickness.

1. Introduction

With the application of resin matrix composites expanding, the thick section matrix composites are also in increasing demand. The wild range of application is not only in the aerospace, but also in the ship, civil engineering, automobile industry and other fields [1-2]. At the same time, due to the brittle characteristics and being sensitive to impact, the matrices of composite material are easy to damage and the skill of composite material repair is very important. In fact, many technology of composite material repair has been achieved [3]. The repair method of composite material and the curing process will directly influence the the recovery of composite strength and stiffness. The temperature fields of resin matrix composite patch of different thickness are influenced by many factors during the curing process. In literature [4] thermal-chemical and flow compaction finite element model are established to analyze the composite temperature field. The research results show that, compared with thin section patch, the thick section patch has a large cure and temperature gradient only in the thickness direction, and the local temperature is easy to be high, which seriously affect the mechanical properties of composite laminates.

In this paper, the physical models of resin matrix composite material repairing for different thickness are established, and numerical simulation analysis is carried out for the temperature field of two kinds of patch thickness during the curing process by using the finite element method. The temperature fields of different thickness patch during the curing process are studied, which provides reference for different thickness of composite material repair.

2. Physical model and boundary conditions

2.1 The establishment of physical model

Full depth scarfing for composite is to dig out the injury area and fill the new composite materials, in order to recovering the material’s strength and stiffness. The establishment of appropriate physical model for numerical simulation calculation of the temperature field is very important.

Figure 1 is a physical model of full depth scarfing, which adopts the scarf repair joint mode. So there is a dig angle. In this paper, there are two kinds of thickness patch physical model, and both model’s patching angle is 20 degrees. The size of the model is that: thick section repair model’s length * width * height =210mm * 200mm * 20MM, and thin section patch model’s length * width * height

=210mm * 200mm * 2mm. As shown in Figure 2, the X direction in the figure is the width. The Y direction is the height (thick) direction, and the direction of the length is Z.

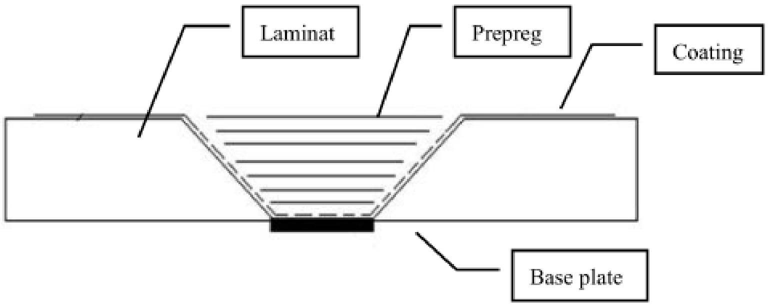

Fig.1 Schematic diagram of full depth scarfing

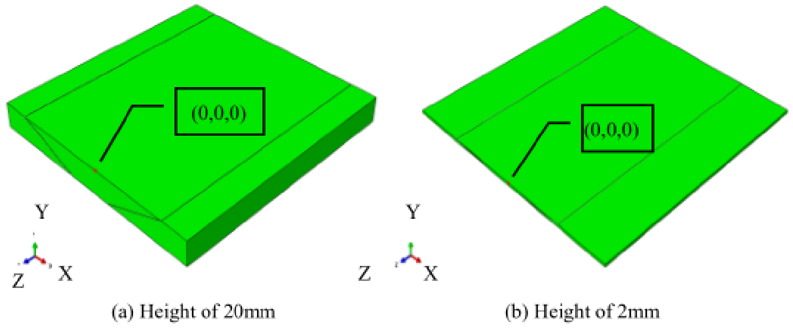

Fig.2 Full depth scarfing model of different thickness patches

2.2 Boundary condition

The curing of composite patch is done by the vulcanizing machine.

1) The temperature boundary conditions: the lower surface is defined as the adiabatic conditions of laminates.

$$k_{yy}\frac{\partial T}{\partial y}=0 \quad (1)$$

2) The convective heat transfer boundary condition

The upper surface and four side surfaces are defined as the first class boundary condition of laminates.

$$T_t = T_s = T_h(\mathrm{t}) \quad (2)$$

Among them, T_h(t) express as the lower surface temperature of the vulcanizing machine, which is determined by the curing process curve.

Heat transfer boundary conditions give the thermal state on every border. Before curing the beginning temperature of patch is equal to the room temperature and the curing degree is 0, that is, the initial condition is:

$$T_0 = T(x,y,z,0),\ \alpha|_{t=0}=0 \quad (3)$$

3. Calculation of temperature field

3.1 The heat conduction equation

The heat conduction equation is based on the principle of thermal balance [5]. According to the theory of heat balance, the transient heat conduction of three-dimensional finite element an-isotropic materials control equation with an internal heat source:

$$k_{xx}\frac{\partial^2 T}{\partial x^2}+k_{yy}\frac{\partial^2 T}{\partial y^2}+k_{zz}\frac{\partial^2 T}{\partial z^2}+q=\rho c_p\frac{\partial T}{\partial t} \quad (4)$$

In the type, ρ, c_p, T and t express as density, specific heat, temperature and time; $\dot{q}$ is the exothermic reaction rate, which is the heat of curing reaction per unit time and per unit volume; k_{xx} , k_{yy} , k_{zz} express as the thermal conduction coefficient of the material in 3 main directions.

The curing reaction heat release rate is related to the curing reaction rate, the formula is [6]:

$$\dot{q} = \rho\left(1-V_f\right)H_R\frac{d\alpha}{dt} \tag{5}$$

In the formula, V_f is the fiber volume fraction; H_R is the total reaction heat per unit mass of resin curing, and its value is determined by experiment; α is the degree of curing, which is the degree of the curing reaction.

3.2 The cure kinetics equation

Curing reaction of the resin is a very complex chemical reaction. Therefore, most of the relevant reaction kinetics equations are established on the basis of experience model. A general mathematical model for the kinetics of the curing reaction can be expressed as [7]:

$$\frac{\partial\alpha}{\partial t} = f(\mathrm{T},\alpha) \tag{6}$$

Among them, f (T, α) is a function of temperature and the degree of cure, and its concrete form depends on the resin material system. Carbon fiber / epoxy resin's curing kinetics of empirical formula is [8]:

$$\frac{d\alpha}{dt} = A\exp\left(-\Delta E/RT\right)\alpha^m\left(1-\alpha\right)^n \tag{7}$$

Among them, R=8.31 $J*mol^{-1}K^{-1}$, which is the universal gas constant; ΔE is activation energy; A is the frequency factor; *m* and *n* express as the reaction orders.

3.3 Process curve and material parameters

The vulcanizing machine is used to finish the cure. The process curve contains a heating stage, heat preservation phase and cooling phase, as shown in figure 3.This patch is the resin matrix composite material (material: 3234/T300B), the mechanical property parameters as shown in table 1.

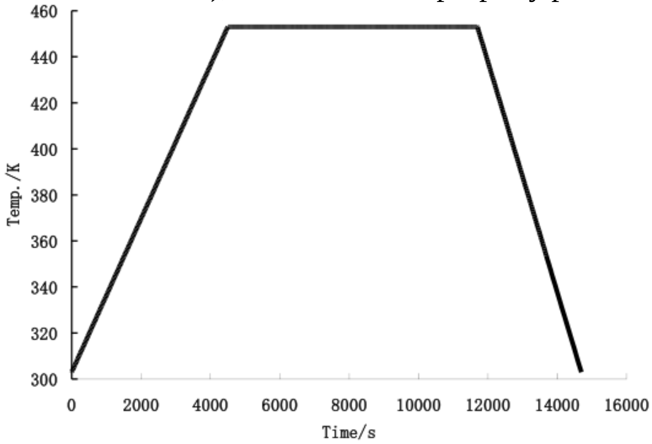

Fig.3 The temperature curve of curing process

The heating rate of the heating stage is 2K/min. After the temperature from room temperature (303K) up to 453K, it will keep 453K for 2 hours, and in the cooling stage, the cooling rate is 3K/min; eventually drop to 303K at room temperature.

Table 1 the mechanical property parameters of 3234/T300B

ρ kg/m^3	C_P $J/(kg*K)$	k_{xx} $W/(m*k)$	k_{yy}、k_{zz}	A	ΔE	m	n
1230	1260	5.43	0.41	$1.49*10^{10}$	94750	0.45	1.877

4. Results and analysis

4.1 The internal temperature distribution during heating stage

The internal temperature distribution of the different thickness patches during the curing process are obtained by the finite element simulation calculation, Figure 4 and figure 5 show the temperature distribution at x=0 section for thin section patch and thick section patch at 1500s respectively.

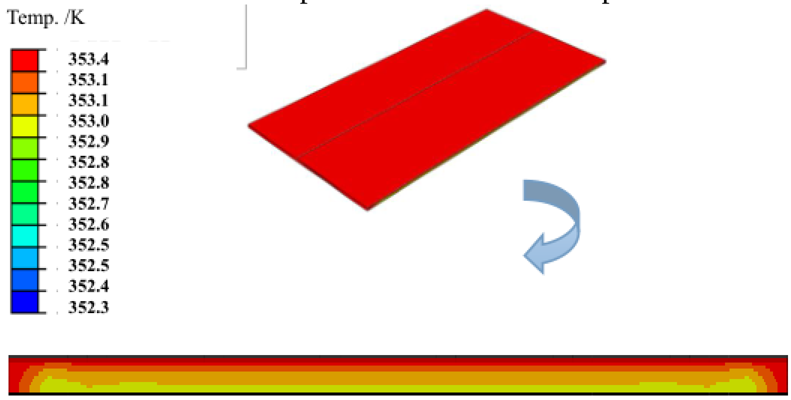

Fig.4 The temperature distribution of the thin patch at 1500s (x=0 section)

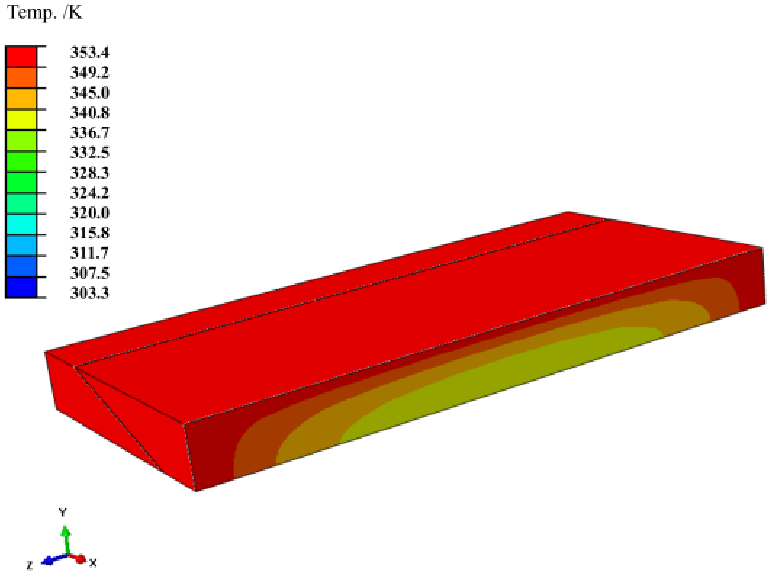

Fig.5 The temperature distribution of the thick patch at 1500s (x=0 section)

From Figure 4 and 5 it can be seen that both thickness composite patch have temperature gradients at the same time of the heating stage, and the temperature gradient at thickness direction (Y direction) is greater than the horizontal (X, Z direction). Compared with the thin section patch, the thick patch's temperature gradient is larger; the temperature difference is relatively large from inside to outside

4.2 The internal temperature distribution during heat preservation phase

Figure 6 and figure 7 show the temperature distribution at x=0 section for thin section patch and thick section patch at 6000s respectively. It can be seen that the patches are in the same temperature. However, the same temperatures are arrived at different time for the two patch thickness. The time is 4600s for the thick section patch, and the time for the thin section patch is 5600s, which means that the heating rate is larger for thick section patch than the thin one.

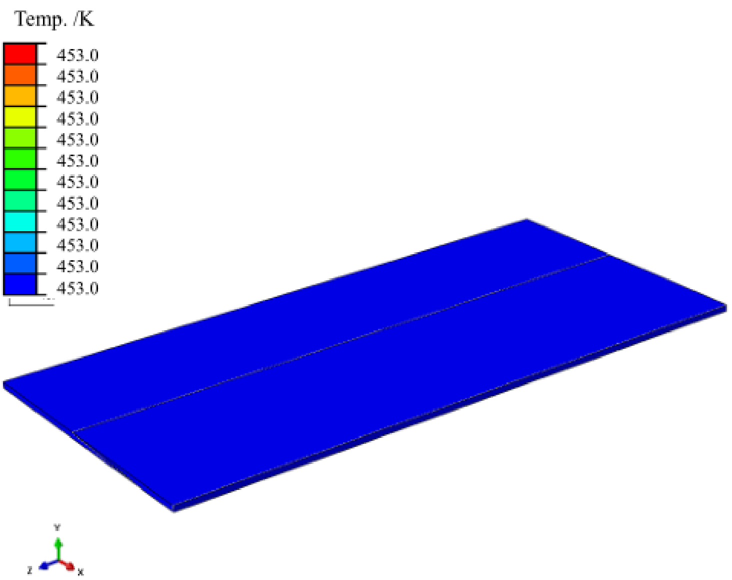

Fig.6 The temperature distribution of the thin patch at 6000s

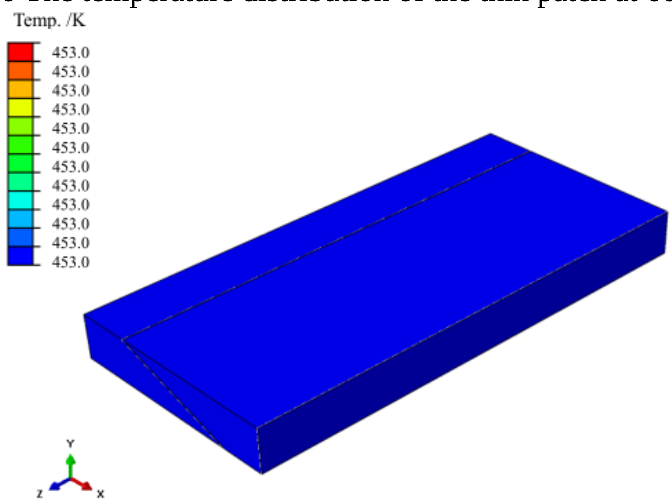

Fig.7 The temperature distribution of the thin patch at 6000s

4.3 The internal temperature distribution during cooling phase

Figure 8 and figure 9 show the temperature distribution at x=0 section for thin section patch and thick section patch at 12000s respectively. It can be seen that both thickness composite patch have temperature gradients at the same time of the cooling phase, and the temperature at the bottom side is larger than that at the top side because of the internal curing reaction heat, Compared with the thin section patch, the thick patch’s temperature gradient and the internal temperature are also larger.

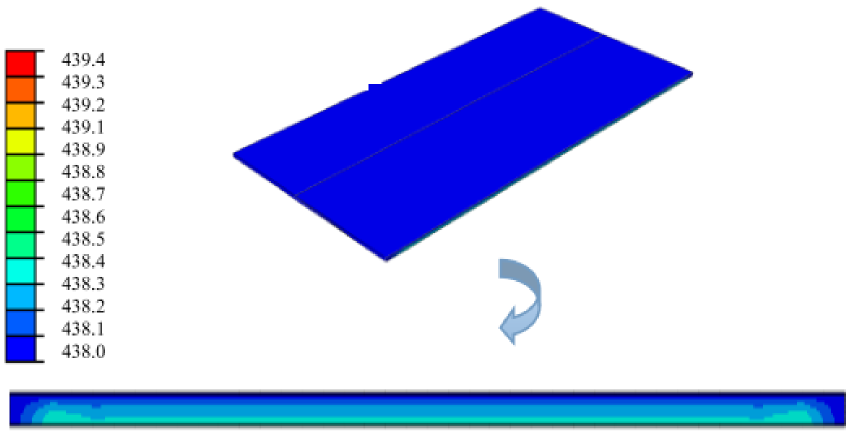

Fig.8 The temperature distribution of the thin patch at 12000s

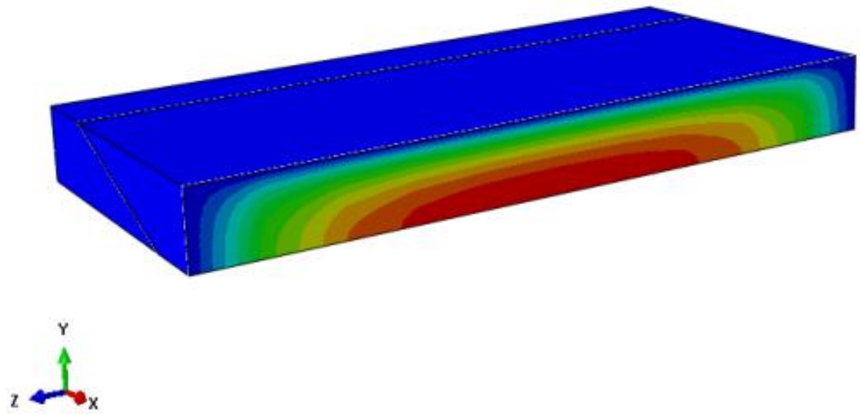

Fig.9 The temperature distribution of the thin patch at 12000s

5. Conclusion

(1) During the curing process of the composite patch, different thickness patches have temperature gradient, and the temperature gradient of the patch at thickness direction is greater than the horizontal direction. Compared with the thin section patch, the thick patch's temperature gradient is larger.

(2) The internal temperature in the thick patch is obvious higher than that in the thin patch during the curing process.

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