Asian Journal of Chemistry; Vol. 26, No. 17 (2014), 5687-5690

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.18184

Process Study on Curing Composite Material T-Stiffened Panel†

W.F. PENG[1,2,*], L.H. ZHAN[1], L.R. ZENG[2] and H.M. BAI[2]

[1]State Key Laboratory of High Performance and Complex Manufacturing, College of Mechanical and Electrical Engineering, Central South University, Changsha, P.R. China
[2]Zhejiang Provincial Key Lab of Part Rolling Technology, Faculty of Mechanical Engineering and Mechanics, Ningbo University, Ningbo, P.R. China

*Corresponding author: Fax: +86 574 87608358; Tel: +86 15088831361; E-mail: pengwenfei@nbu.edu.cn

AJC-15773

Stiffened composite panels are the main structure of aerospace bearing components. Furthermore, the forming quality of the R region is important yet difficult. This paper focused on the research of the temperature and curing degree of the R region of a co-curing stiffened panel. By using finite element analysis, this paper builds an FE model with thermal-chemical coupling and analyzes the temperature field distribution of a cross-section and the curing degree field distribution of a composite. The FE model investigates the co-curing of a longitudinal section of a T-stiffened panel. Through point tracking, the heating rate's effect, the curing process temperature on the resin curing temperature, the curing degree and the curing rate are determined. The results lay a theoretical foundation for further research over the forming quality of the R region.

Keywords: T-Stiffened panel, Composite, Curing, Process.

INTRODUCTION

High strength and light weight composite materials that are capable of bearing heavy loads are crucial for aerospace engineering. The incorporation of these materials into the aerospace field has led to the development of modern-day advanced aircrafts in both military and civilian sectors. These widely-used aircrafts incorporate high-performance carbon fiber reinforced resin matrix composites.

For both the F-22 and F-35 aircrafts, composite weight accounts for 26 % of the aircraft structure's weight; additionally, it accounts for 35-40 % for the European ET-2000 fighter, 25 % for the A380 airliner and greater than 50 % for the B787[1].

These components need to be fabricated at a large size with complicated structures and great load capacity. For example, the size of the central wing box is nearly 8 m × 7 m × 2.4 m and weighs 8.8 × 10^3 kg. Using composites, this member may use only 5.3 × 10^3 kg of material, allowing for a 15 % weight loss. The composite material must also be able to support the coexistence of various detailed structures including beams, ribs, stringers and skin. The composites must also possess great load strength. Using the Airbus A380 as an example, a maximum takeoff weight of 560 × 10^3 kg and a takeoff thrust of up to 120 × 10^3 kg must be supported. The span-wise force at the composite central wing box is 50-100 × 10^3 kg/m and the tangential shear flow is 60 × 10^3 kg/m.

These large composite structures not only need to survive extreme load during flight, but they also need to possess a long service life and remain very reliable. Extreme performance pushes the aircraft's scale, shape and performance control to the extreme. Large composite components need various rib, frame, stringer and skin structures to coexist in them. Competition of manufacturing technology involving aerospace composites has become focused on the production of large, high-performance integral load-bearing components.

Loos and Springer[2] has established a one-dimensional model to simulate the curing process of a flat plate composite. Bogetti and Gillespie[3,4] studied two-dimensional anisotropic cure simulations of thick composite laminates. Zhu *et al.*[5] developed a three-dimensional coupled thermo-chemo-viscoelastic model to simulate composite heat transfer, curing, residual stresses and curing deformation. However, there is a relatively small amount of research available about the co-curing of stiffened composite panels. This paper builds a finite element (FE) model coupling the thermal-chemical characteristics of co-curing a T-stiffened panel, studies the curing process and

†Presented at 2014 Global Conference on Polymer and Composite Materials (PCM2014) held on 27-29 May 2014, Ningbo, P.R. China

analyses the features of the temperature field and curing degree field which lay the theoretical foundation for further research of the curing deformation.

EXPERIMENTAL

Curing mathematical model of composite materials

Model of thermal-chemical coupling: The internal temperature distribution of the composite during the preform stage directly affects the degree of curing. An uneven temperature field will cause uneven curing, which will eventually lead to thermally-induced residual stresses in the composite components. The temperature field of the curing resin is changed because the resin releases heat exothermally as it is cured. This problem can be modeled as a heat conduction problem with a nonlinear, internal heat source resulting from the exothermic curing reaction. The essence of the thermal-chemical coupling model is the Fourier equation of heat conduction with a nonlinear, internal heat source that is a function of curing rate. The thermal-chemical model can be expressed as[3,4]:

$$\rho(\alpha,T)c(\alpha,T)\frac{\partial T}{\partial t}=\frac{\partial}{\partial x_i}\left(k_{ij}\frac{\partial T}{\partial t}\right)$$

$$+\rho(\alpha,T)H_u\frac{d\alpha}{dt}\quad (i,j=1,2,3) \qquad (1)$$

where T represents the absolute temperature of the composite material, ρ is the equivalent density, c is specific heat capacity and k_{ij} is the coefficient of thermal conductivity. All of these affect the temperature field and degree of cure. H represents the total released heat of the matrix resin curing reaction and dα/dt represents the instantaneous curing rate.

Kinetic model of curing: The curing process of the composite material is complex involving the coupling effects of the heat, force and chemical reaction. Modeling the kinetic model of curing of 3501-6 as a piecewise function, curing rate can be expressed[6-8]:

$$\frac{d\alpha}{dt}=\begin{cases}(K_1+K_2\alpha)(1-\alpha)(0.47-\alpha) & (\alpha\le 0.3)\\ K_3(1-\alpha) & (\alpha>0.3)\end{cases} \qquad (2)$$

$$K_i=A_ie^{\frac{-\Delta E_i}{RT}}\quad (i=1,2,3) \qquad (3)$$

where K_i represents reaction rate constant of resin, A_i represents the frequency factor of the resin system, ΔE_i represents resin activation energy, R represents constant of ideal gas, R = 8.31 J/mol K and α represents the degree of cure.

Finite element model: The geometry model is shown in Fig. 1 where the skin size is 100 mm × 5mm × 200 mm, the flange size is 60 mm × 5 mm × 200 mm, the web size is 4 mm × 33 mm × 200 mm and the fillet radius is 3 mm.

Three-dimensional finite element modeling of co-curing a T-stiffened panel is established in this paper. The model is defined as follows: (1) The symmetry constraint is applied in the symmetric plane of the T-component. (2) The effect of curing deformation is neglected. (3) The component is meshed with the hexahedral elements (Fig. 2). There are 11700 elements. (4) Anisotropic heat conduction is considered. (5) The resin matrix is assumed not to flow during the curing process.

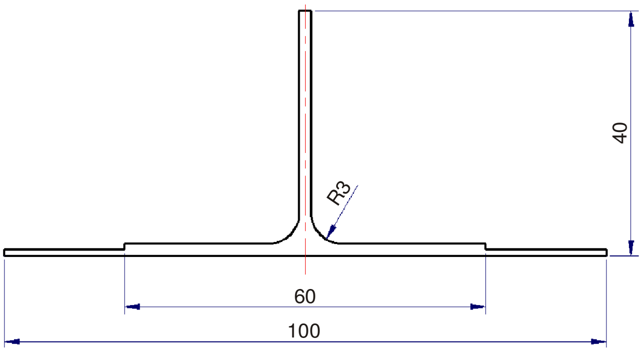

Fig. 1. Geometry model of component

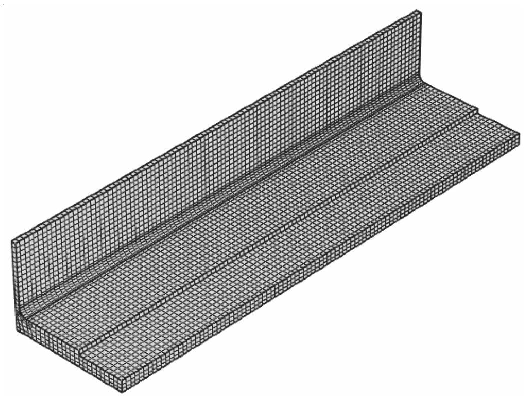

Fig. 2. Mesh the component

(6) Convective heat transfer is neglected. (7) The solver is explicit. Curing process temperature loading on the preform surface is shown in Fig. 3.

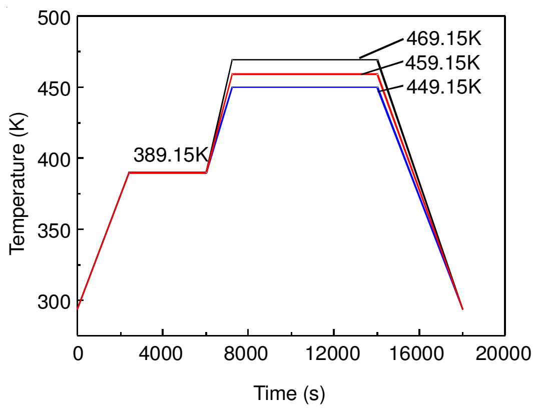

Fig. 3. Process of temperature loading

RESULTS AND DISCUSSION

Distribution of temperature: Through the FE numerical simulation, the temperature distribution of the cross section is obtained. With the heat loading, the heat transfers from the surface into to internal material. However, because the preform is a poor heat conductor, its surface temperature is higher than the internal temperature.

According to the temperature loading process curve, while the curing process is progressing into the first level preservation temperature, the internal resin curing reaction is releasing heat, making the internal temperature higher than the surface temperature. During the second stage of the heating during curing process, the surface temperature will be higher than the internal temperature of the preform. While the curing process progresses into the second level preservation temperature, the internal resin curing reaction releases heat, causing the internal temperature to be higher than the surface temperature. While the curing process running into the cooling stage, the internal material cools slower than the surface, making the internal temperature higher than the surface temperature. Finally, the temperature of the entire material will converge. It also can be seen that the temperature difference in the binding region between the skin and T-ribs is relatively large. The temperature difference across the skin thickness is relatively smaller.

Distribution of curing degree: Through the finite element numerical simulation, the curing degree distribution of the longitudinal section is obtained. With the heat loading, the heat transfers from the surface of the material into the bulk material. The surface curing degree is higher than internal curing degree.

According to the temperature loading curve of the curing process, while the curing process progresses into the first level preservation temperature, the internal resin curing reaction releases heat, causing the internal curing degree to be higher than the surface curing degree. While the curing process progresses into the second stage of heating, the surface temperature will be higher than the internal temperature of the preform, making the surface curing degree larger than the internal curing degree. While the curing process continues into the second level preservation temperature, the internal resin curing reaction is still producing heat, making the internal curing degree higher than the surface curing degree. Finally, the curing degree of internal and external material joins at a value of 1. It can also be seen that the, skin and T-type ribs with curing area and the surface temperature difference, covering part of the inside and outside of curing degree difference is small. It also can be seen that the curing degree difference in the binding region of skin and T-ribs is relatively large. The curing degree difference of inside and outside skin is relatively small.

Analysis of the curing process: Using the central point (0, 3.5, 100) of the structure as the tracking point, the influence of process temperature on curing temperature, curing degree and curing rate are studied.

Temperature analysis: As shown in Fig. 4, during the heating process, the central point temperature increases over time. Because the matrix resin exothermically releases little energy and the T component is so thin, the peak temperature is not relatively high. The reasons of producing the temperature peak are the heat of internal resin producing curing reaction cannot release in time, the surface temperature can cool easily. Overall, areas with a high curing temperature will experience a larger cooling rate and a high peak temperature.

Curing degree analysis: As shown in Fig. 5, during the heating process, the curing degree of the central point increases over time. Because the curing temperature increases, the curing rate also increases. This allows the composite to reach a higher degree of curing, meaning that the material can fully cure in less time. At the curing temperature (469.15 K), the time of

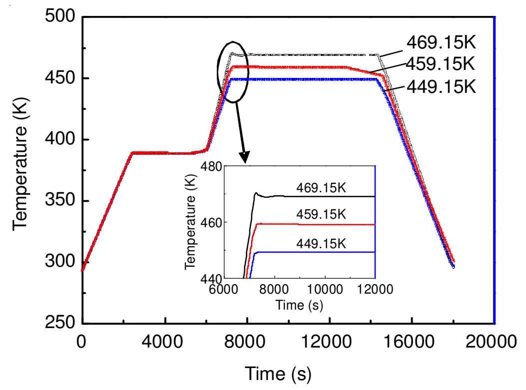

Fig. 4. Temperature of central point with time

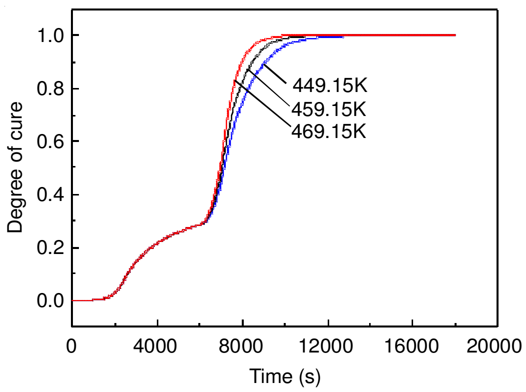

Fig. 5. Curing degree of central point with time

reaching the curing degree 1 is shorter than the time of curing at lower curing temperatures (449.15 and 459.15 K).

Curing rate analysis: Unchanging the heating time, under the premise of increasing the heating rate, the relationship between the curing rate and curing time is shown in Fig. 6. The cure rate in the initial time is small. As curing process, the curing rate gradually increases and reaches the maximum peak at the end of the heating time, then decreases. The curing rate is an increasing function of temperature. The curing rate increases with the increase of the temperature. With the curing process, the curing degree increasing, which make the curing rate decrease. The higher the temperature, more the curing rate.

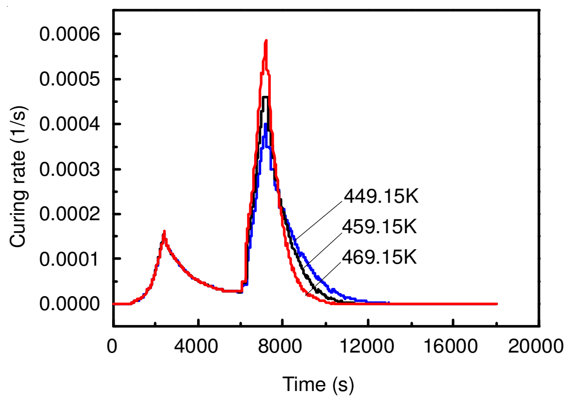

Fig. 6. Curing rate of central point with time

Basically, the higher the heating rate is, the faster the curing rate is. The relationship is shown in Fig. 7. By lowering

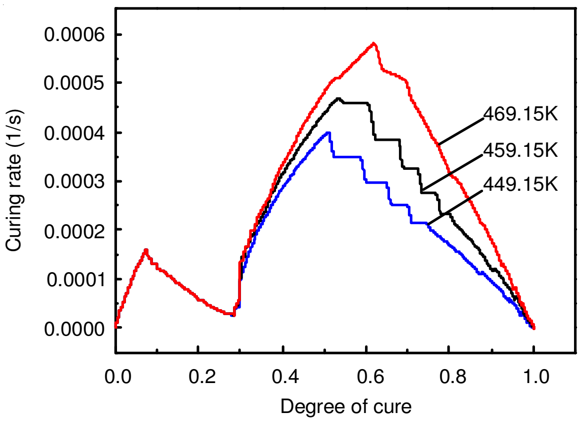

Fig. 7. Curing rate of central point with curing degree

the curing process temperature when the curing degree is smaller, the curing rate will decline because the heating time is short. This results in a small degree of curing when the holding temperature is low. The heating rate and heating time directly affect the curing rate at small degrees of curing. The curing rate reaches a peak at the end of heating time and then the curing rate declines with the onset of the stage of holding temperature. The curing degree, however, is still growing. Finally, the curing process completes in the preform. From the eqn. 2, as the curing degree increases the curing rate decreases. Though the above research, we can determine that the curing rate has a relationship with the heating rate, heating time and curing degree. At a low curing degree, the peak of the curing rate is largely influenced by the heating rate and heating time.

Conclusion

The temperature difference and curing degree difference between the internal composite and surface composite alternate until, finally, the temperature and curing degree distribution converge. A higher curing temperature increases the curing rate and a higher degree of curing can be achieved in the same curing time. This means that less time is required to fully cure the composite. The heating rate and heating time directly determine the curing rate at small curing degrees. The curing rate reaches a peak at the end of heating time and then declines as the composite is held at the holding temperature. At a low curing degree, the curing peak is largely influenced by the heating rate and heating time.

ACKNOWLEDGEMENTS

Project (2014CB046502) sponsored by 973 Program, project(2014RS4031) sponsored by Hunan Postdoctoral Scientific Program, project(Kfkt2013-04) supported by Open Research Fund of Key Laboratory of High Performance Complex Manufacturing, Central South University and sponsored by K.C.Wong Magna Fund in Ningbo University.

REFERENCES

1. X.Z. Liang, Z.H. Zhang and T.S. Liu, *Aeronautical Manufact. Technol.*, **20**, 26 (2011).
2. A.C. Loos and G.S. Springer, *J. Compos. Mater.*, **17**, 135 (1983).
3. T.A. Bogetti and J.W. Gillespie Jr., *J. Compos. Mater.*, **25**, 239 (1991).
4. T.A. Bogetti and J.W. Gillespie Jr., *J. Compos. Mater.*, **26**, 626 (1992).
5. Q. Zhu, P.H. Geubelle, M. Li and C.L. Tucker III, *J. Compos. Mater.*, **35**, 2171 (2001).
6. E. Ruiz and F. Trochu, *J. Compos. Mater.*, **39**, 881 (2005).
7. J.M. Svanberg and J.A. Holmberg, *Compos. Appl. S*, **35**, 711 (2004).
8. G. Liang and K. Chandrashekhara, *J. Appl. Polym.*, **102**, 3168 (2006).