NUMERICAL SIMULATION OF FORMING PROCESS OF AIRCRAFT TRANSPARENCIES MANUFACTURED BY POLYMERIC PLATE

Yue Yan, Dingguo Zhang, and Guanli Zhang
Beijing Institute of Aeronautical Materials,AVIC I, 100095, Beijing, China

Keywords: *numerical simulation, polymeric plate, aircraft canopy,thermoforming*

Abstract

In this paper, a new forming process of polymeric sheet for aircraft canopy called freely blowing was simulated by adopting the thermo-elasto-visco-plastic large deformation finite element formulation based on Updated Lagrangian method. Some details of this forming process were also studied. It was shown that temperature has important effect on the forming process.

1 Introduction

Transparent engineering plastics such as acrylic and polycarbonate, shows outstanding high transparency, high performance of heat and creep resistance, relatively high elastic modulus and impact resistance strength. They are now widely used in aircraft transparencies. Performing FEM simulation for forming process can provide valuable information for tools design, help quickly and accurately determine blank shape and process parameters, greatly shorten tools tryout cycle, accelerate the development of new product.

Traditional forming process for large polymeric parts refers to thermoforming. But a parts with relatively uniform thickness distribution is so hard to obtain by this forming process.
In this paper, the thermo-elasto-visco-plastic large deformation finite element formulation based on Updated Lagrangian method was employed to simulate the forming process of aircraft canopy made of polycarbonate plate. Some details of the forming process were also studied.

2 Finite Element Formulation and Material Modeling

The adopted thermo-elasto-visco-plastic large deformation finite element formulation based on *Updated Lagrangian* method[1-2] is as follows

$$[K_p]\{\dot{\delta}\}=\{\dot{f}_p\}+\{\dot{g}_p\} \qquad (1)$$

where $[K_p]$ is the global stiffness matrix, $\{\dot{\delta}\}$ is global velocity vector, $\{\dot{f}_p\}$ is derivative of the equivalent nodal force of body and surface force with respect to time, and $\{\dot{g}_p\}$ is a right –hand term resulting from the effect of temperature and strain rate.
The whole forming process consists of heating, keeping-temperature, deformation, and cooling. But the deformation, that is said, freely blowing is the most important step, and was studied especially in this paper. Since there is no contact between blank sheet and the mould in freely blowing deformation, no friction force was considered.

Since polycarbonate's glass transition temperature T_g is 149℃, the blank is first heated to a temperature higher than T_g in this paper. The material is in elasto-visco-plastic state at 165℃. Uniaxial tension test at 165℃ was conducted on the special tensile experiment machine[3]under five strain rate 0.001/s, 0.003/s, 0.005/s, 0.008 and 0.01/s. The experimental result is described as figure 1.

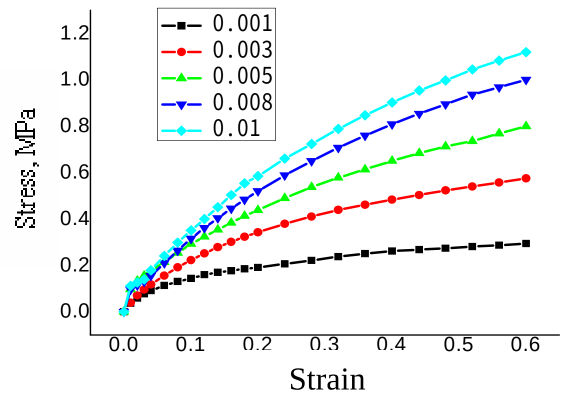

Figure 1 True stress –strain curves of strain rate 0.001/s, 0.003/s, 0.005/s, 0.008 and 0.01/s at 165℃

The material model used[2] in deformation stage was established as follows by fitting the experimental data

$$\sigma = \sigma_0 \left(1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^m \tag{2}$$

where $\dot{\varepsilon}$ denotes strain rate, $\dot{\varepsilon}_0$ denotes reference strain rate, *m* refers to rate sensitivity index. And

$$\sigma_0 = \begin{cases} E\varepsilon & (\varepsilon \le \varepsilon_s) \\ a\varepsilon^{b\varepsilon^{-c}} & (\varepsilon_s \le \varepsilon \le \varepsilon_l) \\ k\varepsilon + d & (\varepsilon \ge \varepsilon_l) \end{cases} \tag{3}$$

where E denotes elastic modulus, ε_s denotes yield strain, a, b, c, d, k and ε_l are material constants. Their values are listed in table 1.

Equation (2) was generalized for 3D case by substituting σ with equivalent stress $\bar{\sigma}$, ε with equivalent strain $\bar{\varepsilon}$, and $\dot{\varepsilon}$ with equivalent strain rate $\dot{\bar{\varepsilon}}$, where $\bar{\sigma} = \sqrt{3/2\sigma'_{ij}\sigma'_{ij}}$, $\dot{\bar{\varepsilon}} = \sqrt{2/3\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}}$, $\bar{\varepsilon} = \int_0^t \dot{\bar{\varepsilon}} dt$.

Uniaxial tension tests at different constant temperatures were performed, and equation $\sigma = f(\varepsilon)$ was established at different temperature levels. Fitting the individual stress-strain curve under different temperatures was demonstrated in Figure 2.

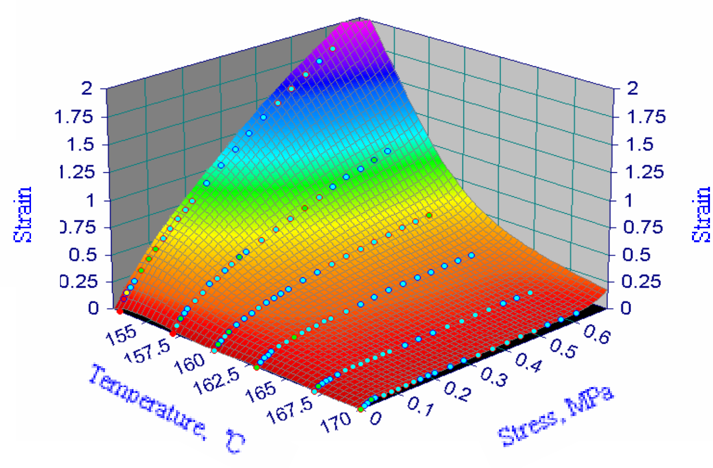

Figure2 3D depiction of relation within stress, strain and temperature for the polycarbonate plate

The relationship between stress, strain and temperature is required to reflect the effect of temperature on equation $\sigma = g(\varepsilon, T)$,as follows

σ =a+b/T+cε+d/T2+eε2+fε/T+g/T3

+hε3+iε2/T+jε/T2 (4)

where *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*,*i*,*j* are constants. Their values are given in table 2.

Table 1. Material Model Parameters

Parameters	***E*** , MPa	ε_s	ε_l	***a*** ,MPa	***b***	***c***	***D***, MPa	***K***, MPa
Value	0.7871	0.0154	0.2357	0.041	0.10121	0.25387	0.03215	0.004425

Table 2. Model Constants

Parameters	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*
Value	-67.6414	122.349	71.8844	425.1399	-2112.8836	1.423	0.2712	3771.602	-2880.1266	7921556.1

3 Simulation results and discussion of the freely-blowing forming process of PC material

Basic material property parameters of the PC plate used are: Poisson's ration μ=0.4, initial blank thickness h=9.5mm. The maximum in length direction of the blank is 2400mm, and the maximum in width direction is 1700mm. The contour of aircraft canopy was shown as Figure 3.

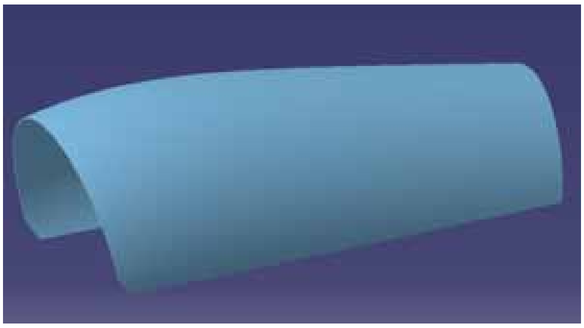

Figure 3. The contour of aircraft canopy

Firstly, the simulation experiments were applied under the temperature 160℃, 165℃ ,and 170℃, but the contours of canopy were not correct. And then for a desired shape, temperature gradient was applied along longitudinal direction in the process of freely blowing deformation.

The upper surface is obtained by offsetting the given product ' s contour 4 mm outward, while the lower one by offsetting the contour 2 mm inward, check if the nodes of the parts have entered a sphere between two surfaces. The ratio of number of nodes entering the sphere to number of total nodes under

Table 3. Deformation under differetemperature

Shape and thickness distribution of the blank sheet at the end of forming stage is shown in Figure 4. It can be seen that the highest location of the parts is the thinnest. The lower the location on the parts, the thicker it is. This agrees with actual product's thickness distribution tendency.

Acknowledgments

This work was carried out with the help of Institute of Auto-body and Die Engineering in State Key Lab of Automobile Dynamic Simulation of Jilin University. This support is gratefully acknowledged.

References

[1] Y. Tomita, A. Shindo and T. Sasayama, 1990. Plane strain tension of thermo-elasto-viscoplastic blocks. Int. J. Mech. Sci. Vol. 32, No. 7. pp. 613-622

[2] Haipeng Liu, 2003. Three Dimensional Finite Element Numerical Simulation for Thermoforming Process of Polymeric Sheet, PhD Dissertation, pp. 29-41 (in Chinese)

[3] Dingguo Zhang, 2006. Study on Finite Element Numerical Simulation for Thermoforming Process of Polycarbonate Plate, Researching paper for undergraduate, pp16- 22 (in Chinese)

Table 3. Deformation under different temperature conditions

Temperature conditions	Ratio of qualified nodes to total nodes
160℃	30.0%
165℃	35. 0%
170℃	36.0%
With temperature gradient	85.0%

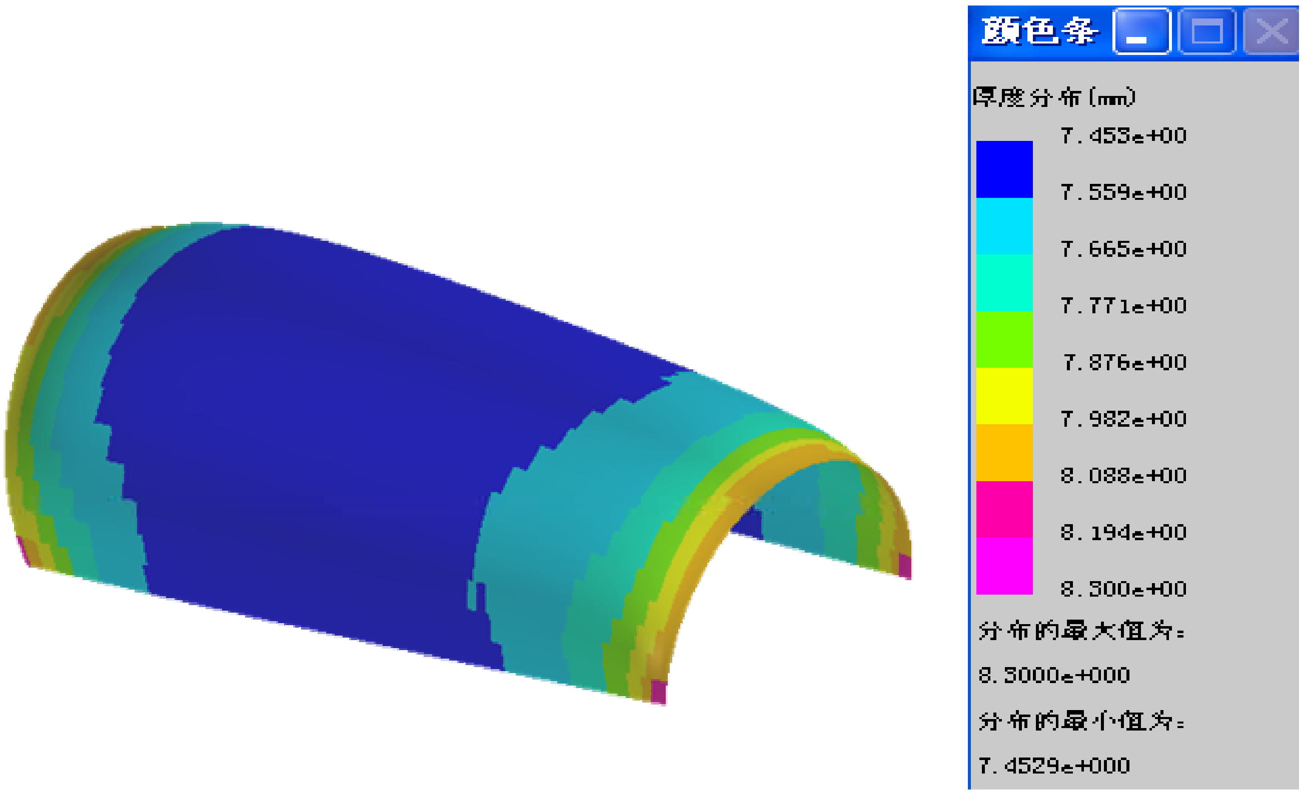

Figure 4. Final surface shape and thickness distribution of the canopy with simulation of freely blowing deformation process