A DESIGN METHOD OF THE COMPOSITES PART MOULD BASED ON THE PART DEFORMATION DURING THE MANUFACTURE PROCESS

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Introduction

Autoclave processing is the usually method to be used for manufacturing the composite parts and curing is the main moulding process. During the curing process, residual stress can be induced by external forces or temperature gradients, and it can lead to the deformation or warpage of the composite parts after demould. It is difficult to control the process-induced deformation. In tradition, majority of methods are mainly based on experiences and experiment to obtain the part with the reasonable shape after manufacturing by two ways: to optimize the process cycle and to compensate the geometry of the mould. Researchers have done much work on predicating the part deformation [1][2][3]. According to these references, a few work contributed on reducing the deformation from the view of mould design and using the trial-and-error effort to eliminate the deformation of the composite component is costly and time-consuming, and the result can only be used for the specific component.

In this paper, a method is introduced to decrease the deformation of the composite part by the mould compensation way. The method includes a predication model and a compensation model. The predication model is utilized to calculate the deformation of the composite part by numerical simulations method, and the compensation model is introduced to reduce the deformation based on the predication value.

Methodology

The method to design the composite part mould with complicated surface can be divided into the following steps:

Step 1: For a given composites part, the mould is designed using the original surface of the composite part. According to the research and practice, if the required accuracy of the parts is not very high, the parts manufactured by this mould are acceptable, especially for the small parts.

Step 2: Using the predication model to predicate the deformation of the composites parts. The predication model is developed based on thermal stress analysis and FEA. Furthermore, the thermal distribution is analyzed by FULENT software, then importing the result (**.cas format) into the ABAQUS software, finally, the thermal stress and the deformation of the composite part are computed by the predication model which integrated into the ABAQUS software.

Step 3: Importing the analysis result from the ABAQUS software (**.rpt format) into the CATIA software (the result includes the 3D coordinate and the deformation value in three axis directions). Verifying the part dimensional accuracy, if the deformation of the part is acceptable, the mould can manufactured directly without surface compensation (step 5). Otherwise, compensate the surface by the compensation model.

Step 4: Re-design the mould using the compensated part surface, then go to step 2.

Step 5: Manufacturing the accepted mould, and then the composite part manufactured by this mould can get the desired shape.

Predication Model

Many researchers introduced that the geometry is one of the primary factors determining the deformation of composites, especially typical structure, such as angled structures, stiffener structures, etc [1]. For parts with generally shape, it may be easy to find out the relationship between the deformation and the parts geometry, but it is difficult or a impossible work for a part with complicated surface. So in this paper, the predication model is established based on FEA method and it is not rely on the parts shape. Suppose stresses and strains are not generated when the resin is in liquid state. So after the part is completely cured, the shape of the mould can be calculated by a linear elastical model. For a mesh of the composites part, to evaluate the cure induced stresses and strains, the three dimension formulation related to the deformations can be calculated by:

$$\varepsilon_x = \frac{\partial u_x}{\partial x}, \varepsilon_y = \frac{\partial u_y}{\partial y}, \varepsilon_z = \frac{\partial u_z}{\partial z}, \gamma_{xy} = \frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}$$

$$\gamma_{xz} = \frac{\partial u_z}{\partial x} + \frac{\partial u_x}{\partial z}, \gamma_{yz} = \frac{\partial u_z}{\partial y} + \frac{\partial u_y}{\partial z} \qquad (1)$$

Where u_i represents the mesh deformation vector and $u_i = \{u_x, u_y, u_z\}$ represents the three displacement parts. $\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{xz}$ and γ_{yz} are the deformed parts. For an anisotropic model, considering the thermal and shrinkage effects, the thermal-chemical model [3] can be described as:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x_i}(k_{ij} \frac{\partial T}{\partial x_j}) + \rho H_R \frac{\partial c}{\partial t} \qquad i, j = 1, 2, 3$$

So the temperature distribution is obtained by this equation. The detailed information is introduced in Ref.[3]. The constructive equation between the stress and strain tensors can be expressed by:

$$\vec{\sigma} = Q(\vec{\varepsilon} + \alpha_t \Delta T) \qquad (2)$$

Where Q represents the stiffness matrix related to Young's modulus, Poisson's modulus and shear modulus of the composites part. α_t is the thermal expansion coefficients. The mechanical equilibrium equations can be defined as follow:

$$\nabla\sigma + F = 0 \tag{4}$$

Where ∇ represents a differential operator, F is the volume force vector induced by the temperature and the chemical shrinkage. The displacements u_i can be calculated by substituting Equ.(1)-(3) into Equ.(4).

Compensation Model

The predication model and compensation model are not associated with the part geometry, and it was based on a FEA method.

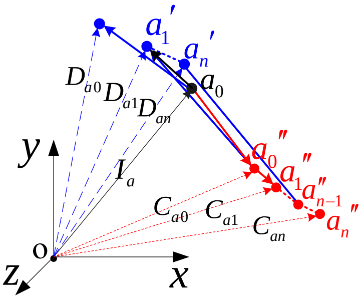

Figure 1 Compensation model of discrete point of the complicated surface

In figure 1, point a is a node of the mesh in the three stages: initial state a, deformed state a' and the compensated state a''. $\overrightarrow{I_{in}}, \overrightarrow{D_{in}}, \overrightarrow{C_{in}}$ $(i = a, b\ldots;\ n = 1, 2\ldots)$ represent the initial vector, deformation vector and the compensation vector of the point i at recursive step n respectively. It can be seen from the predication model, at the first compensation step,

$$\overrightarrow{a_0 a_0'} = D_{a0} - I_a = u_{a0}$$

The compensation value can be defined as

$$\left\|\overrightarrow{a_0 a_0''}\right\| = \left\|C_{a0} - I_a\right\| = \beta\left\|\overrightarrow{a_0 a_0'}\right\|$$

Where β is called the compensation factor, and the factor can influence the convergence speed. The compensation direction is symmetric opposite to the deformation. Now the first compensation vector $\overrightarrow{C_{a0}}$ can be calculated. With this geometry $\overrightarrow{C_{i0}}$ $(i = a, b\ldots)$, a new FE model is carried out, the deformation value u_{a1} can be calculated by the predication model. So the compensation value equation can be formulated recursively as follow:

$$\left\|\overrightarrow{a_n'' a_{n-1}''}\right\| = \left\|C_{an} - C_{a(n-1)}\right\| = \beta\left\|\overrightarrow{a_0 a_n'} + \overrightarrow{a_{n-1}'' a_n'}\right\|$$

The process would stop at step 3 when the accuracy value satisfy the following equation,

$$\left\|D_{in} - I_a\right\|_{\max} < \varepsilon$$

Where ε represent the max acceptable tolerance.

Result and discussion

The aircraft skin with complicated surface is studied. The composite material is 3501-6 epoxy and its properties are shown in table 1. The max acceptable tolerance ε is set as $0.5mm$. In step 1, the max deformation is 2.256mm shown in figure 2, so the surface should be compensated, setting the compensation value $\beta = 1$. The deformation value is 2.073mm after compensation shown in figure 3, and the max deformation errors from the initial surface is $0.183mm$ shown in table 2, and the value is bellow ε, so the surface compensated in step 1 can be used to design the mould, the designed result is shown in figure 4.

Table 1 The cure kinetics constants for 3501-6 epoxy [4]

$A_1(\min^{-1})$	$A_2(\min^{-1})$	$A_3(\min^{-1})$	$\Delta E_1(J\bullet Mol^{-1})$	$\Delta E_2(J\bullet Mol^{-1})$	$\Delta E_3(J\bullet Mol^{-1})$
2.102×10^9	-2.104×10^9	1.960×10^5	8.07×10^4	7.78×10^4	5.66×10^4

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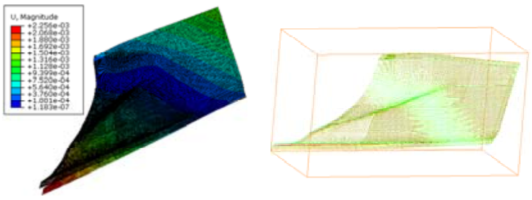

Figure 2 The initial deformation and The compensation surface in step 1

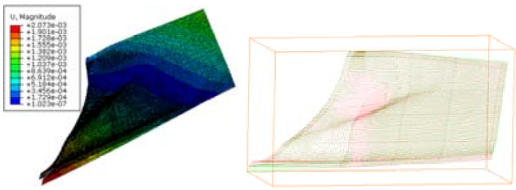

Figure 3 The final deformation and The compensation surface in step 3

Table 2 The analysis result

Result	Step 1	Step 2
Deformation	Figure 2	Figure 3
$\left\|D_{in} - I_a\right\|_{\max}$	2.256mm	0.183mm

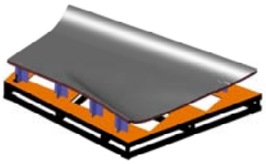

Figure 4 The designed mould utilized the compensated surface

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