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SIMULATION ANALYSIS OF WIND TURBINE BLADE DURING RESIN TRANSFER MOLDING PROCESS

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Abstract. The wind turbine blade is a key component of wind turbine generator system, and helps capture wind energy effectively. The way of RTM resin transfer molding is generally used at home and abroad for blade manufacturing process. In order to ensure the quality of product, computer simulation analysis and experimental verification should be conducted before producing. Moldflow was used to simulate the process of wind turbine blade RTM. Based on that, variation diagrams about filling time, temperature, buckling deformation, pressure and so on are obtained. The results of analysis and comparison of with and without cooling, as well as optimize the defects existed indicate that cavitations concentrate in roots and edge of the blade, gas exhaust mold easily, there is no need to open up air vent additional; In filling stage, mold clamping force gradually increase slowly, in packing stage, mold clamping force sharply increase to reach peak, the mold clamping force disappears after packing; filling time with cooling process is longer than that without cooling process. It provides an important reference for wind turbine blade design and manufacture.

1. Introduction

Compared with many composite manufacturing processes available, resin transfer molding(RTM) is one of the most efficient and economical process due to its capabilities such as non-expensive process equipment, closed mold process, excellent control on mechanical properties, incorporation of metal inserts and attachments, low filling pressures, possibility of producing large and complex parts and low labor costs [1].

Macro-flow (resin flow between the fiber bundles) and micro-flow (resin flow within the fiber bundles) both exist during the process of resin transfer molding. Flow behavior is influenced by a lot of factors and flow principle is completely complex, so that many problems are to be solved. This comes to be the focus of study on liquid model molding process field at home and abroad [2, 3].

Analysis of resin transfer molding of blade has deep significance on development of RTM. Computer is used to simulate the molding process. Continuous modification and perfection of numerical method in practice helps computer to analyze and predict the process of molding exactly. After resin has injected into cavity during RTM process, shape of resin in saturated zone and flow front change over time, which is a transient process. The numerical method of treating free surface and moving boundary of transient fluid is the key of simulation of resin transfer molding process. To solve this problem, first of all, the whole time zone is divided into a series of small time slices. The fluid flow is regarded as steady-state process in these small time slices, that is to say, a series of brief steady-state process to approximate simulation of the non-steady-state problem of entire flow. So that, Darcy law can be used to solve equations of each steady-state process. Fixed grid method is obtained to figure out this kind of matter. Thus a kind of powerful and effective Control Volume/Finite Element Method (CV/FEM) is developed [4]. Behavior of resin flowing in the cavity is forecasted by simulation. Reasonable arrangement of injection and vent location is obtained, as well as proper molding process parameters. So that to guide mold and process designs.

Z. Dimitrovova and L. Faria discussed how to use the ANSYS to simulate the RTM process with the method of analogy [5]. Cevdet researched on bending property and impact property of molding of carbon fiber fabric/epoxy composites at different resin injection pressure(101, 203, 304, 405, 506 kPa) [6]. Lee and Wei considered product performance of high performance epoxy resin at injection pressure 294 kPa, 392 kPa, and 490 kPa. They also discussed effect fiber structure made on composite material mechanics performance and void content at different injection temperature (150 ºC and 160 ºC). Conclusion was molding of composite material plate have best mechanics performance at 392 kPa [7].

Through the further research of scholars from home and abroad in recent decades, a large number of simulation analytic results about injection molding process are acquired. The simulation analytic results based on all kinds of methods have been largely used in actual engineering [8]. But the research on mold filling process of wind turbine blade and the status of blade in this process is not enough. Start with current status of the research on injection molding process of blade, this article research the change rule of all kinds of related factors in the mold filling process, such as temperature, warping deformation, pressure and so on, and as well as comparison of all kinds of factors what are in the two conditions – with or without cooling liquid process. The research results will be conducive to the further research of injection molding of blade.

2. Mathematical model

Resin's flow in the mold cavity can be seen as Newtonian fluid's flow in porous media. This kind of flow is simulated and analyzed by using Darcy law. Darcy law can be described by the following formula.

$$\mathbf{v} = -\frac{\mathbf{k}}{\mu} \cdot \nabla p \,. \tag{1}$$

In this formula, $\mathbf{v}$ is velocity vector, ∇p is pressure gradient, μ is viscosity, $\mathbf{k}$ is permeability tensor of fiber cloth.

Due to the density of fiber and resin is assumed to be constant. The following is continuity equation:

$$\nabla \cdot \mathbf{v} = 0 \,. \tag{2}$$

The following equation is obtained by combining Eq. (1) and Eq. (2) and regional integration:

$$-\int \mathbf{n} \cdot \frac{\mathbf{k}}{\mu} \cdot \nabla p \, ds = 0 \,. \tag{3}$$

Based on the Eq. (3), it can be assumed that the function of pressure's changing in unit is able to solve the problem of fluid flow through the anisotropic porous medium is made. So pressure is the parameter which should be solved at the end.

N-S equation is the motion equation which describes momentum conservation of incompressible fluid, as follows:

$$\begin{cases} \rho\left(\dfrac{\partial \nu_x}{\partial t}+\nu_x\dfrac{\partial \nu_x}{\partial x}+\nu_y\dfrac{\partial \nu_x}{\partial y}+\nu_z\dfrac{\partial \nu_x}{\partial z}\right)=\rho g_x-\dfrac{\partial p}{\partial x}+\mu\left(\dfrac{\partial^2 \nu_x}{\partial x^2}+\dfrac{\partial^2 \nu_x}{\partial y^2}+\dfrac{\partial^2 \nu_x}{\partial z^2}\right)+\dfrac{1}{3}\mu\dfrac{\partial}{\partial x}\left(\dfrac{\partial \nu_x}{\partial x}+\dfrac{\partial \nu_y}{\partial y}+\dfrac{\partial \nu_z}{\partial z}\right), \\ \rho\left(\dfrac{\partial \nu_y}{\partial t}+\nu_x\dfrac{\partial \nu_y}{\partial x}+\nu_y\dfrac{\partial \nu_y}{\partial y}+\nu_z\dfrac{\partial \nu_y}{\partial z}\right)=\rho g_y-\dfrac{\partial p}{\partial y}+\mu\left(\dfrac{\partial^2 \nu_y}{\partial x^2}+\dfrac{\partial^2 \nu_y}{\partial y^2}+\dfrac{\partial^2 \nu_y}{\partial z^2}\right)+\dfrac{1}{3}\mu\dfrac{\partial}{\partial y}\left(\dfrac{\partial \nu_x}{\partial x}+\dfrac{\partial \nu_y}{\partial y}+\dfrac{\partial \nu_z}{\partial z}\right), \\ \rho\left(\dfrac{\partial \nu_z}{\partial t}+\nu_x\dfrac{\partial \nu_z}{\partial x}+\nu_y\dfrac{\partial \nu_z}{\partial y}+\nu_z\dfrac{\partial \nu_z}{\partial z}\right)=\rho g_z-\dfrac{\partial p}{\partial z}+\mu\left(\dfrac{\partial^2 \nu_z}{\partial x^2}+\dfrac{\partial^2 \nu_z}{\partial y^2}+\dfrac{\partial^2 \nu_z}{\partial z^2}\right)+\dfrac{1}{3}\mu\dfrac{\partial}{\partial z}\left(\dfrac{\partial \nu_x}{\partial x}+\dfrac{\partial \nu_y}{\partial y}+\dfrac{\partial \nu_z}{\partial z}\right). \end{cases} \quad (4)$$

In the formula, ρ is fluid density, p is pressure, ν_x, ν_y, ν_z are velocity components of fluid at time *t*, at point (*x*, *y*, *z*), g_x, g_y, g_z are external force components.

Molding cycle also is molding process, which includes mode locking, clamp, platform feed, injection, pressure maintaining, colloidal sol + cooling, push-out, die sinking, platform back. The size of product is 80.3 mm × 950.47 mm × 64.27 mm. It is suitable for 3D analysis as the shape is thick and stubby. Because of model problems, such as geometry and size, some defects appeared after the mesh division is completed, for instance overlapped elements, crossed elements, free edge, unreasonable aspect ratio, incoherent circulation, etc. If these problems are not properly solved, the quality of the model will be influenced badly, so that the analytic results may be not correct.

3. Interpretation of results

Simulation results of wind turbine blade molding process, as shown in Fig. 1-6 separately.

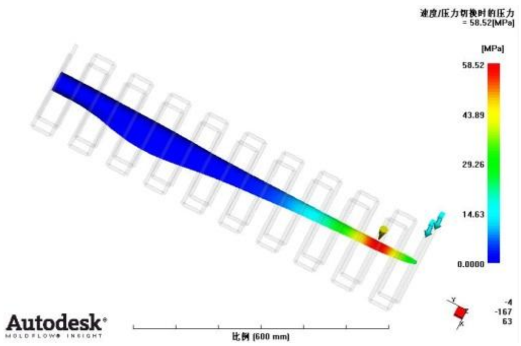

Fig. 1. Analysis of pressure when switching from velocity to pressure.

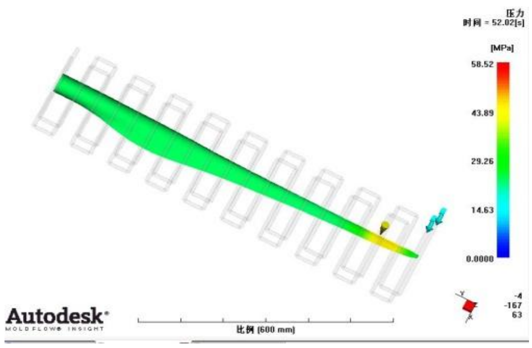

Fig. 2. Analysis of pressure.

As shown in Figs. 1, 2, pressure when switching from velocity to pressure is also the pressure of the end of filling, the magnitude of which is linear to distance from the injection gate. The longer the distance is, the smaller the pressure is. After the process of pressure maintaining, as a whole, pressure distributes evenly, there aren't large areas of 0 MPa and maximum pressure. Quality of the blade is improved.

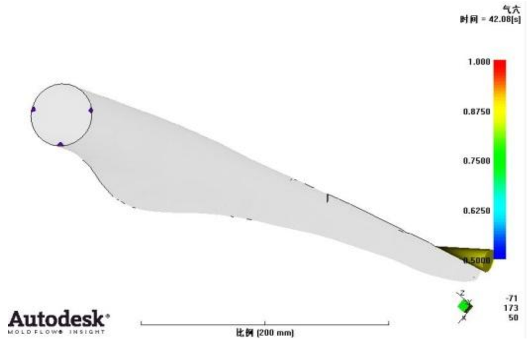

Fig. 3. Analysis of cavitations.

As shown in Fig. 3, cavitations distribute at root and edge of the blade. So that air could be ejected from the mold easily and there is no need to use vents.

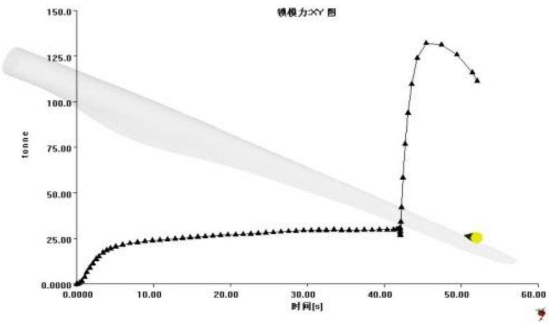

Fig. 4. Analysis of mold clamping force.

The larger maintaining pressure is the smaller cubical contraction of plastic injection products is obtained [9]. As sho n in Fig. 4, clamping force change hugely at 42 s which is also the time when switching from filling process to pressure maintaining process. Clamping force increases from slowly to rapidly to avoid resin from running over. Clamping force disappears after the process of pressure maintaining.

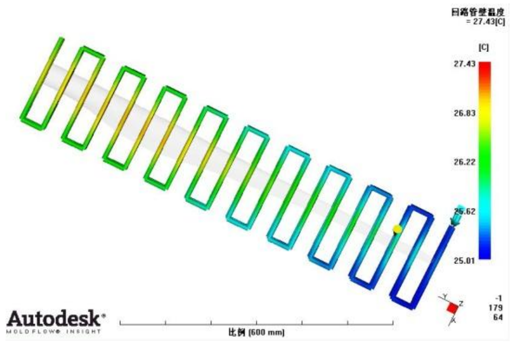

Fig. 5. Analysis of pipe wall temperature.

As shown in Fig. 5, the range of temperature is 2.42 degrees which is reasonable. Temperature of entrance is low, but the temperature increases as the distance away from the entrance increases. Besides, it presents entirely that the color of middle part of pipeline is bright; the color of both sides of pipeline is dark. That is to say, temperature of pipelines lie above the blade is higher than both sides of pipeline.

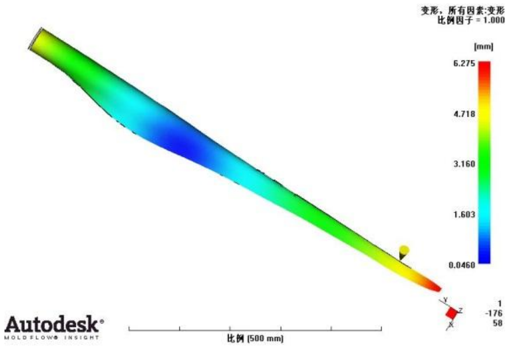

Fig. 6. Analysis of warping.

As shown in Fig. 6, warpage is largest at the part of blade tip, and which is smallest at the middle where close to the root of blade.

4. Comparative analysis

A general mold filling process involves cooling. The results of two situations, with and without cooling are represented in Figs. 7, 8 below to enable a visual comparison.

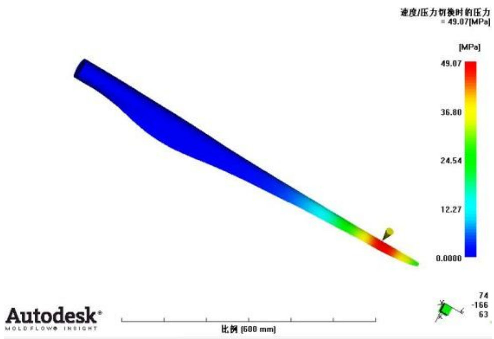

Fig. 7. Analysis of pressure when switching from velocity to pressure without cooling process.

Under the conditions of cooling and no cooling, general change law of mold filling process is the same by comparing Fig. 7 with Fig. 1. Due to the lower temperature, resin viscosity increases and resin flow rate decreases. When switching from velocity to pressure, pressure under the condition with cooling is larger than without cooling.

As shown in Fig. 8, molecular orientation shrink anisotropy is offset by cooling process, which contributes to improving warping deformation.

5. Optimization design

The variety of cavity types and designs of runner have quite a little effect on filling results [10-12]. As shown in the analysis results above, there are still some defects exist during filling process, such as the pressure when switching from velocity to pressure is rather large, warping deformation is not small. These defects are optimized by transforming gating system into which adopting runner with double gates, as well as adding cooling water channels. The optimized results are shown in Figs. 9, 10 below.

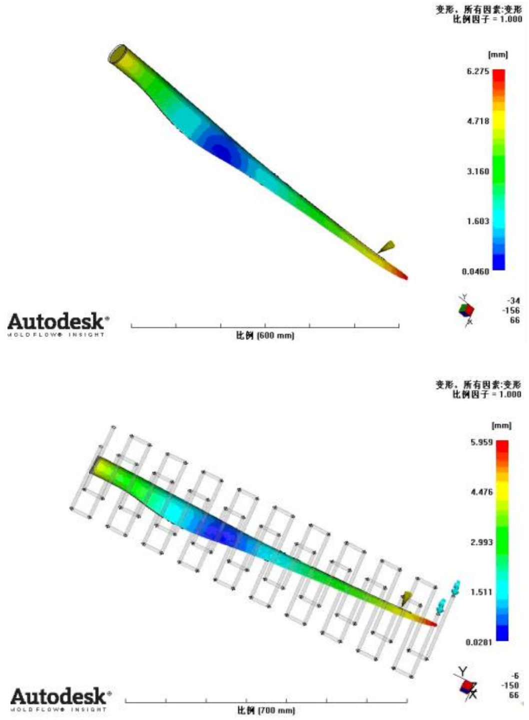

Fig. 8. Comparative analysis of warping.

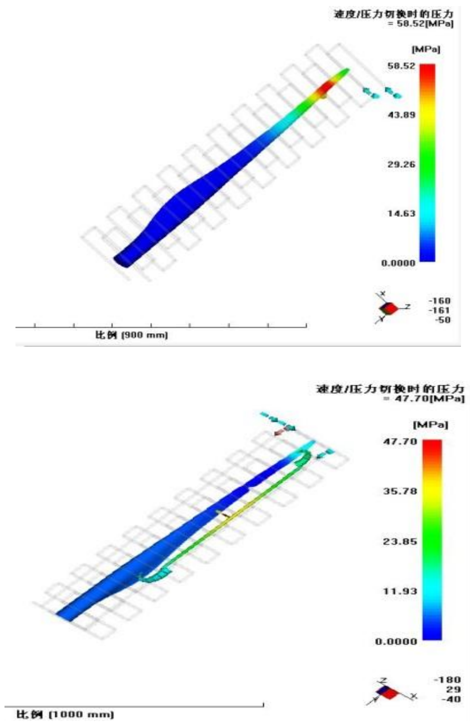

Fig. 9. Comparative analysis of pressure when switching from velocity to pressure before and after optimizing.

As shown in Fig. 9, after optimizing, the pressure when switch from velocity to pressure decreases. Efficiency is potentiated as well as wastage is reduced.

As shown in Fig. 10, two pictures clearly explain that warping deformation of blade is improved. As a result, quality of products gets great a degree enhanced through effective and reasonable optimization.

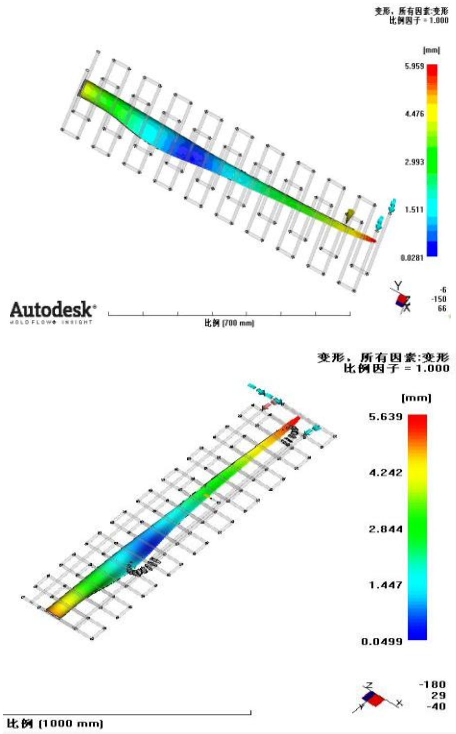

Fig. 10. Comparative analysis of warping before and after optimizing.

6. Conclusions

(1) By simulating and analyzing resin transfer molding process of wind turbine blade, the change rules of pressure, temperature and warping during molding process are researched.

(2) Contrastive analysis of filling results under the conditions of cooling and no cooling is obtained.

(3) The defects which have influence on the quality of products are optimized by changing technical process.

(4) Conclusions like maintaining process homogenize the products so that quality is improved, is reached by simulating and analyzing the molding process. Through the comparative analysis of filling processes with and without cooling, several conclusions are obtained, for example, filling time is longer, warping deformation is smaller, quality of product is better with cooling process.

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