Influence of Process Parameters of Unidirectional Glass Fiber Fabric on Resin Infiltration Rate

Xia Qianjin¹, Hao MingYang²*, Zhang HongSheng³, Zhong Hai²

¹. Department of Aeronautical Engineering, College of Large Aircraft, Ordos Institute of Technology, Ordos 017000, Inner Mongolia, China
². ChongQing Polycomp International Corporation, Dadukou District, Chongqing 40082
³. Faculty of Mechanical and Material Engineering, HuaiYin Institute of Technology, HuaiAn, JiangSu, China, 223003
haomingyang@cpicfiber.com

Abstract. The tensile and compressive strength, torsional strength, and fatigue strength of wind turbine blades are closely related to the infusion defects during the manufacturing process of blade girders. Inadequate understanding of the resin infiltration process of the glass fiber fabric is one of key factors leading to the infusion defects. This article mainly studies the influence of fabric weft TEX, weft angle, stitch length, and stitch tension on the resin infiltration rate through experiments. The results show that the resin infiltration rate in the 90° direction of fabric increases as weft TEX and weft angle increase and that the infiltration rate in the thickness direction increases when stitch length and stitch tension increase.

1. Introduction

Wind power is a type of clean energy with smaller environmental burdens. In 2019, wind power generation accounted for about 4.5% of the total power generation in China. Wind turbine blades, as core components of wind turbines, have a decisive impact on service life and power generation efficiency of wind turbines. The blade girder of wind turbine, made of composite materials of glass fiber resin matrix, is a primary force-taking structure which is usually produced through a vacuum infusion process with unidirectional glass fiber fabric. Wind power blades are developing in the direction of large-scale size [1]. With the increase of the blade size, the width of unidirectional glass fiber fabric is gradually increasing, so the requirements for infusion of the fabric are getting higher and higher.

The resin infiltration rate is a physical property which indicates flow resistance degree of the fabric or reinforcement materials in the resin. The resin infiltration to reinforcement materials has a decisive effect on the quality and efficiency of parts during production.

Now the Vacuum-Assisted Resin Transfer Molding method (VARTM) is primarily adopted to produce wind turbine blades. [3] Its main process is to place fabric on the die and next to put a layer of demolding cloth on the top layer of the fabric. Then cloth with high infiltration rate is put on the top, and the last step is infusion by vacuum pumps before wrapping with vacuum bags and sealing.

The flow speed of the resin has a great influence on the infiltration result and labor costs of wind turbine blade girders. Slower infiltration rate in the 90° direction of the fabric can easily cause unthorough infiltration of fabric which shows white color, while faster infiltration rate in the same
direction can lead to the resin going through the glass fiber quickly, resulting in poor infiltration as well. Therefore, fabric manufacturers should adequately adjust their fabric process parameters according to requirements of clients to meet the needs of the infusion of blade girders and reducing labor costs.

At present, the research on fabric infiltration is mainly divided into non-experimental methods and experimental methods\[2\]. This study mainly explores the influence of fabric process parameters on the resin infiltration rate by experimental tests, and the results can provide references for glass fiber fabric manufacturers.

2. Experiment

2.1. Experimental Design

A type of frequently used unidirectional high-mode glass fiber fabric is selected for the tests. The thickness of the fabric is 0.2mm, and the width in 90°direction is 650mm. The total weight per unit area is 1200g/m², in which the weight in the longitudinal direction is about 1164g/m² and about 51g/m² in the latitudinal direction.

The manufacturing of unidirectional fabric involves process parameters and equipment. Since the weft TEX, weft angle, stitching tension, and stitching length are the main factors that affect the resin infiltration to the fabric, this study will investigate the influence of the above four factors on resin infiltration rate from the experimental perspective\[4\].

The ranges of the four factors to be measured are listed in Table 1. In the experiment, the single factor design was used to study the effect of a certain factor on the resin infiltration rate, namely conducting experiment with different values of one factor while keeping the other factors unchanged. The first set of values of the four factors in Table 1 was used as reference. When

| Table 1 the first set of values of the four fabric factors |
|----------------------------------------------------------|
| Value 1 | Value 2 | Value 3 |
| Weft tex | 136     | 200     | 300     |
| Weft angle | 88     | 90      |
| stitching length | 4.6   | 4.8     | 5.0     |
| stitching tension | 1~2   | 2~4     | 5~6     |

2.2. Experimental

At present, the vacuum resin infusion process is generally used to produce wind turbine blades. Fig.1 shows directions of the fabric layering. During infusion, the resin flows primarily in the direction of the internal pressure gradient and along the thickness direction of the fabric, and the pressure gradient caused by vacuum pump is consistent with the 90° direction of the fabric when producing the blade girder. Therefore, this paper measures the resin flow rate in both the 90-degree direction and the thickness direction of the fabric to represent resin infiltration rate.
2.2.1. **Resin flow rate $K_{22}$ in the 90° direction.** In the experiment, 20 layers of fabric were stacked together, and they were infiltrated with the resin along the 90° direction of the fabric. The faster the resin flowed in the fabric, the longer distance of the fabric infiltrated in the 90° direction was. The variable $K_{22}$ in this article denotes the average rate of resin infiltration in the 90° direction of the fabric in five minutes.

2.2.2. **Resin flow rate $K_{33}$ in the thickness direction.** The resin started infiltrate from the bottom of 20-layer stacked fabric which was kept in vacuum pressure. The time of the infiltration was measured. Since the thickness of the fabric stack is constant, the faster the resin flowed, the shorter time the infiltration took. $K_{33}$ in the article denotes the average rate of resin infiltration in the thickness direction of the fiber.

3. **Data Analysis**

3.1. **The effect of weft tex on infiltration rate**

As can be seen from Fig. 2, as the weft TEX increases, the resin flow rate $K_{22}$ in the 90° direction increases, while the resin flow rate $K_{33}$ in the thickness direction has no significant change. The results show that the weft TEX has a significant impact on $K_{22}$ but hardly affects $K_{33}$.

3.2. **The effect of weft angle on infiltration rate**

As can be seen in Fig. 3(a), $K_{22}$ in the fabric with 90° weft yarn is larger than that with 90° weft yarn by about 17%. However, $K_{33}$ in the thickness direction with 90° weft yarn is 2.7% smaller than that with 90° weft yarn (see in Fig. 3(b)).
3.3. The effect of stitch length on infiltration rate

Fig. 4 shows that $K_{22}$ in the 90° direction is slightly different at stitch length 4.6mm and 4.8mm, but it is significantly reduced at stitch length 5.0mm. The tendency is opposite for $K_{33}$ which decreases when stitch length increases.

3.4. The effect of stitch tension on infiltration rate

It can be seen from Fig. 5 that $K_{22}$ has minor change when the stitch tension increases, indicating that the stitch tension has little effect on $K_{22}$. However, $K_{33}$ increases prominently as the stitch tension increases. This is because the number of slits caused by the stitching threads is the same at certain stitch length, and greater stitch tension cause larger slits. So the resin infiltrates faster along the thickness direction.
Fig. 5 Resin flow rates at different values of stitch tension along (a) the 90° direction and (b) the thickness direction

4. Conclusion
A type of frequently used unidirectional high-mode glass fiber fabric is selected for the tests. The thickness of the 20-layer fabric is 4mm, and the width in 90° direction is 650mm. From the experimental analysis above, some conclusions can be drawn:

1) $K_{22}$ and $K_{33}$ should be adjusted together to achieve a better resin infiltration effect during the production of blade girders of wind turbines;

2) Increase of $K_{22}$ can be obtained by augmentation of weft TEX and weft angle;

3) Increase of $K_{33}$ can be achieved by increasing stitch length and stitch tension.

References
[1] H. Zhou, H. Wang, etc., Research process in composite material wind turbine blade, Material Advance A, 2012, 26(2): 65-6.
[2] D. Qi, R. Ning, H. Ning, Study onVRAM technique for blade of wind power, Chinese Cementing Compound, 2008, 17(6):50-52,56.
[3] Ngo Nd, Tarma K K. Microstructure-based evaluation of the influence of woven architecture on permeability by asymptotic homogenization theory. Composites Science and Technology, 2002 (62):1347-1356.
[4] Hayward JS and Harris B. Effect of process variables on the quality of RTM mouldings. SAMPE J 1990; 26(3): 39-46