EXPERIMENTAL ANALYSIS AND CONTROL OF WHITISH INDUCEMENT AT CORNER OF BLUNT TRAILING EDGE OF FAN BLADE

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It is a difficult problem to study the cause of whitening of the corner of blunt trailing edge of fan blade after vacuum perfusion molding. The causality analysis method is used to summarize and analyze the causes of the whitening of the corner of blunt trailing edge of fan blade and determine the main factors affecting it. Through in-depth analysis and experimental demonstration of raw materials (pouring resin, core material, etc.) and layering structure design used in the process of making fan blades, the measures to effectively control the blanking at the corner of blunt trailing edge of fan blades are put forward. The results show that all the influencing factors can have certain influence on the corner whitening of the blunt trailing edge of the fan blade. This study can provide reliable basis and theoretical basis for the study of product quality and blunt trailing edge of fan blade.

Key words: Fan blade; Blunt trailing edge; Resin defoaming; The moisture content; Floor structure design

1. Introduction

Since September 2020, China has clearly put forward the goals of "carbon peaking" in 2030 and "carbon neutrality" in 2060[1], as well as increasing the

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requirements for planning and building a new energy supply and consumption system, and the wind power industry has ushered in a historic development opportunity[2]. With the rapid development of the wind power industry, the newly developed wind turbines have an increasing capacity and longer wind turbine blades. As the core component of wind turbine, wind turbine blades account for 15%~20% of the total cost [3], the stand-alone power of wind turbines continues to increase, and the blade length matching with wind turbines is also increasing. Wind turbine blades is thin shell structure made of composite materials, generally composed of main beam, trailing edge beam, shear web and leaf root prefabricated parts, composite materials in the weight of the whole fan blade generally accounted for more than 90%[4]。As the market demand for wind power clean energy increases, the size of fan blades is getting bigger and bigger, from the 25-meter blade of 800KW model to the 102-meter blade of 10MW SR210 model[5]。

Due to the increase of blade size, the blade root began to adopt blunt trailing edge design. The so-called blunt trailing edge[6-7] refers to: in the aerodynamic shape design of wind turbine blades, the trailing edge of wind surface is selected as a corner airfoil with 25%~40% relative thickness in the blade transition section connecting the circular section of blade root and the maximum chord section of blade。The characteristics of blunt trailing edge design are to increase blade strength and improve blade starting characteristics without increasing blade weight. The blunt trailing edge design also has the advantages of increasing the cross section moment of inertia, improving the structural characteristics, increasing the cross section lift coefficient and reducing the sensitivity of the airfoil performance to the leading edge roughness[4]。With the introduction of blunt trailing edge design concept, the blade trailing edge thickness is further increased, and the requirements for blade trailing edge layering and core material layering structure, perfusion molding process control and raw material inspection are also further improved。

According to industry survey data, about 40% of fan blade damage accidents occur at the trailing edge of the blade, which is very prone to ultimate failure and fatigue instability. Fatigue failure is easy to occur at the position of maximum blade trailing edge thickness[7]. Therefore, the research on fatigue and failure cause of blunt trailing edge of fan blade root is a hot issue at present。

Fig. 1 Schematic diagram of blunt trailing edge structure

2. Incentive analysis

Aiming at the problem of whitening at the corner of the blunt trailing edge of the fan blade after vacuum perfusion molding, this paper analyzes the key issues of whitening at the corner of the blade, determines various influencing factors, and uses the analysis method of Fishbone Diagram[8] (A Fishbone Diagram is a visual tool used to categorize the potential causes of a problem to determine its root cause.) to summarize them, and determines the influencing factors mainly from the following aspects: Abnormal raw materials (resin, glass fiber cloth, core material), defects in structural design, and influence of corner temperature on blunt trailing edge. Therefore, this paper carries on qualitative and quantitative analysis according to the above factors combined with test methods.

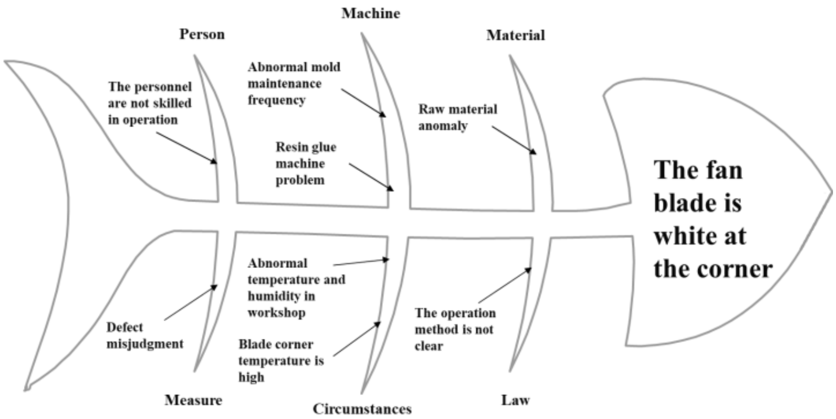

Fig. 2 Schematic diagram of causation analysis

3. Probuse posterior margin corner whitish inducing test

At present, domestic and foreign megawatt-level wind turbine blades mostly adopt vacuum infusion molding process, and in the laying molding process, they are greatly affected by the influence of ambient temperature and humidity[9]. After measurement, the temperature of the molding workshop of Guoneng United Power Technology (Chifeng) Co., LTD. in April ~ May is about 25℃, and the humidity is about 50%. In order to further verify the influence of bubbles, core material moisture content and ply structure on the whitening of the blunt tail edge corners of the fan blades, field simulation experiments were carried out in the laboratory and blade molds.

Experimental material preparation: Vacuum pump, Electric blanket, 3AX-1350-3550 triaxial glass fiber cloth, Vacuum bag film, Sealing strip, Epoxy resin (LT-5078A), Curing agent (LT-5078B-3), Disposable plastic cup, Rubber head dropper, Timer.

3.1. Effect of resin bubble infusion on whitening of blunt trailing edge corner

The commonly used perfusion resin for fan blades is epoxy resin, which has a series of excellent characteristics, such as diversified form, small curing shrinkage, high bonding strength and cohesion strength, excellent corrosion resistance and dielectric properties, and good comprehensive performance [10-12]. Its main component is amine, the viscosity of the main agent of epoxy resin at room temperature is 1100~1800Pa·s, the viscosity is very large, and the bubbles in the resin are difficult to precipitate. There are two main reasons for bubbles: one is that the resin will integrate a large amount of air during production and transportation, although the resin contains a defoamer, but because the viscosity of the resin main agent is relatively large, the air in the resin can not be completely discharged. Second, in the process of resin mixing and resin infusion, due to the relatively backward equipment and tools or improper operation methods, air is mixed into the glue, resulting in the bubbles in the resin being difficult to eliminate. Epoxy resin main agent has the characteristics of increasing temperature, viscosity gradually decreases, when the temperature reaches 60~70℃, the viscosity of epoxy resin main agent is about 200~400mPa·s, in a certain negative pressure state, bubbles attached to the epoxy resin main agent are easy to precipitate. Because the main agent of epoxy resin is easy to mix with air, if a resin mixed with air is used in the process of making fan blades, bubbles will precipitate during the resin curing stage, making it easy to gather at the high point of the blade or the corner position in the blunt tail edge, which eventually leads to whitening and bubble defects on the surface of the product structure.

3.1.1 Test design

In order to further investigate the effect of air bubbles contained in the resin on the wettability of the resin. Simulate the actual leaf production process, use degassing treatment and non-degassed resin for perfusion, and observe whether white spots will occur on the surface of the trial sample, which will affect the wetting effect of the glass fiber layer.

In the first step, two trial samples (area is) composed of 10 layers of triaxial cloth are laid on the test bench, and the laying effect of each trial sample is guaranteed to be the same during the laying process. In the second step, the two trial samples were laid with auxiliary materials in the same conduction method to ensure that the resin could completely infiltrate the glass fiber layer. Then, take a certain amount of resin and curing agent, mix evenly according to the proportion requirements of the TDS instructions, and divide into two parts, one for two-component deaeration treatment, and the other part without deaeration treatment. The resin used in the trial sample 1 was degassed, and the resin used in the trial sample 2 was not deaerated treatment. Next, after the infusion is completed, an electric blanket is used to cover the surface of the prototype sample for auxiliary heating to solidify and mold. Finally, after curing, the surface auxiliary material is torn off, and a single prototype sample is trimmed to make two trial samples of the same size.

3.1.2 Test result

By comparing and analyzing the trial production sample 1 (as shown in Fig. 3) and trial production sample 2 (as shown in Fig. 4), the trial production sample 1 (using resin after defoaming treatment) has a good molding effect, and no related infiltration defects occur on its surface. Trial production sample 2 (using undefoamed resin) has a poor molding effect, with more white streaks on its surface.

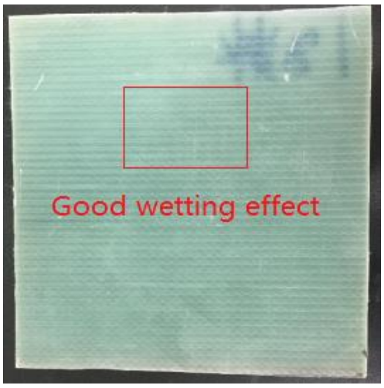

Fig. 3 Trial-produced sample I

Fig. 4 Trial-produced sample II

3.2. Effect of moisture content of core material on whitening of corner of blunt trailing edge

Balsa wood and foam are commonly used core materials in fan blades. Balsa wood is also known as Balsa wood. Balsa wood is highly consistent with the required characteristics of fan blades due to its stable volume shape, easy deformation, moderate strength and flexibility[13]。In blunt trailing edge structures, Balsa wood is usually filled between layers of glass fiber cloth in the corner area of the blunt trailing edge. However, Balsa wood is easy to absorb water, resulting in high moisture content. In the process of leaf curing and heat release, water is easy to vaporize and escape to the fiber and Balsa wood interface, fiber and resin interface, and fiber and fiber gap in the corner area of blunt trailing edge, resulting in white or delamination defects in the corner area of blunt trailing edge, affecting product quality.

3.2.1 Test design

In order to further quantify the effect of core material moisture content on the whitish corner of the blunt tail edge. In order to better simulate the effect of moisture in the core material on the whitening of the blunt tail edge corners, the reaction form of the resin during the curing process was observed when different contents of water were injected into the resin during the test.

First of all, take a certain amount of resin and curing agent according to the proportion requirements of TDS instructions and mix evenly, and place them in 4 plastic cups, numbered: 1#, 2#, 3#, 4#. The resin weight of each plastic cup is 130g. Immediately afterwards, use the dropper to drop 10 drops of water on the 2# plastic cup, 20 drops on the 3# plastic cup, and 50 drops on the 4# plastic cup (about 0.05ml per drop, converted to a mass of about 0.05g), and stir well (stirring should be carried out slowly to prevent stirring too fast to produce bubbles). Then, the above 4 cups of resin are cured at room temperature, the curing time (as shown in *Table 1*) is recorded and the morphology of the resin after curing is observed (as shown in Fig. 5).

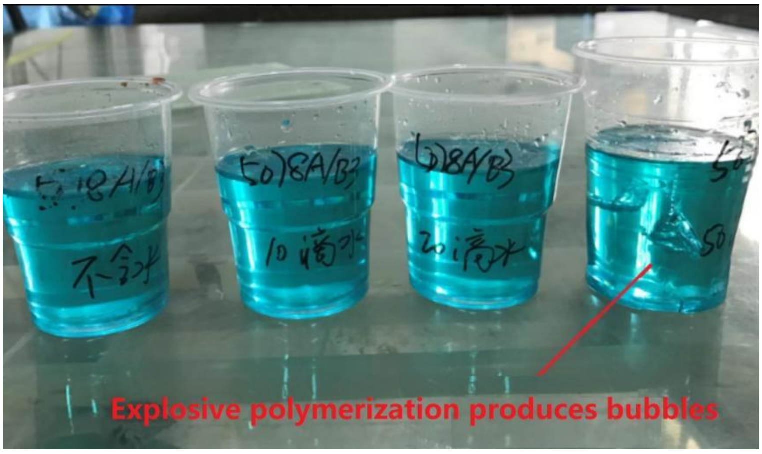

Fig. 5 Morphology of cured resin at room temperature

Table 1

Test data of influence of different moisture content on resin curing

Unit: min

Unit	Resin mixture weight	Introduction	Cure time	Note
1#	130g	No water	469	Normal form
2#	130g	10 drops of water	431	Normal form
3#	130g	20 drops of water	313	Normal form
4#	130g	50 drops of water	195	With explosive polymerization, bubbles

Note: Room temperature 25±2°C

Through the moisture content calculation formula:

$$\zeta = \frac{m_{\text{water}}}{m_{\text{Mixture of resins}} + m_{\text{water}}} \times 100\% \quad (1)$$

The water content of each experimental group was 0%, 0.38%, 0.76% and 1.8%, respectively.

3.2.2 Test result

Through the experimental analysis and theoretical calculation, in a certain range, moisture can effectively promote the curing reaction of resin, shorten the curing time; When the moisture content in the resin is 1.3%~1.5%, the resin will produce bubbles in the curing process because of the explosive polymerization, resulting in the curing of the leaf white phenomenon.

3.3. Effect of paving structure on whitening of corners at blunt trailing edges

In the design stage of large fan blades, in order to improve the structural characteristics and reduce the weight of the blades while maintaining the aerodynamic characteristics of the wind turbine, the thickness of the trailing edge of the blade root is increased, and the blunt trailing edge design can meet the above requirements. The blunt trailing edge design has the advantages of increasing the moment of inertia of the section, improving the structure characteristics, increasing the lift coefficient of the section and reducing the sensitivity of the airfoil performance to the roughness of the leading edge. In the manufacture of fan blades, the blunt trailing edge structure usually adopts outer fiber fabric + core material + inner fiber fabric structure or adopts all fiber fabric structure. In the layering of leaves, due to the presence of blunt trailing edge corner, there will inevitably be gap between cloth layer or core material. In the process of perfusion, the gap area will be filled with resin, and the resin will react and release a lot of heat, which will eventually lead to the white defect in the corner area of blunt trailing edge, affecting the product quality.

Taking National Energy United Power Technology (Chifeng) Co., Ltd. as an example, it produced UPblade-3000-76A (LZ) and UPblade-3000-76 (LZ) blades from 2020 to 2021. The aerodynamic shapes of these two blades are exactly the same, and the trailing edge position is designed with blunt trailing edge. Now, 18 consecutive produced leaves of these two leaf types are selected respectively, and the white defect at the corner of blunt trailing edge is counted (as shown in *Table 2*), which is summarized as follows：

Table 2

Quality defect statistics of the two blade types

Quality defects	Leaf blade model	
	76A(LZ)	76(LZ)
Blunt tail edge corner whitening number	0	8

By comparing the structural designs of 76A(LZ) and 76(LZ) leaf shapes, it is found that the layering structure at the corner of blunt trailing edge of blade is different. For 76A(LZ), the layering at the corner of blunt trailing edge of blade is all made of glass fiber cloth without core material (as shown in Fig. 6), while for 76(LZ), the layering at the corner of blunt trailing edge of blade is made of internal and external glass fiber. There is a core material in the middle (as shown in Fig. 7). Therefore, the following ideas are proposed: Blunt trailing edge corner area layer structure because contain factors of core material in layer between cause in the process of glass fiber cloth and glass fiber cloth, glass fiber cloth and between the core material, core material with large space between the core material, clearance form resin gather location, resin reaction too quickly produce a lot of heat, heat is out in time led to the corner area temperature is too high, Which leads to explosive polymerization leading to whitening defects.

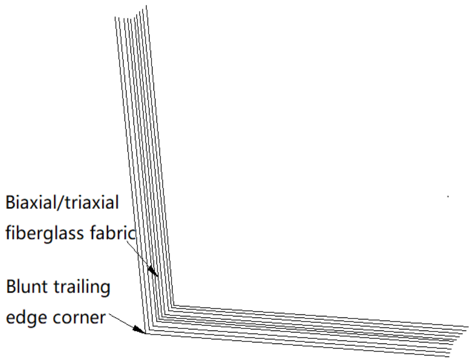

Fig. 6 Lay-up structure without core material

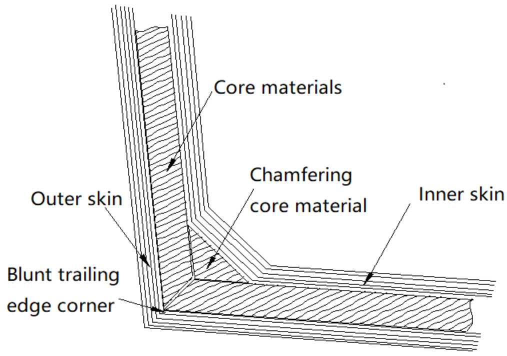

Fig. 7 Lay-up structure with core material

3.3.1 Test design

In order to further study the influence of blunt tail edge layer laying structure on the whitening of blunt tail edge corners, in the actual production process of blades, it is verified that laying core material in the corner area of the blunt tail edge of blades may cause bursting and whitening defects in the corner area of the blunt tail edge.

Firstly, make 6 type 76 (LZ) blades on 1# and 2# molds respectively. When laying the middle layer of 1# mould, ensure that there is no gap between the cloth layer at the corner position of blunt trailing edge and the core material in the layering process (as shown in Fig. 8). When laying the middle layer of 2# mould, there is a certain amount of gap between the cloth layer and the core material at the corner position (as shown in Fig. 9).

Fig 8. No clearance left in layering

Fig. 9 Layering with gaps

Secondly, during the period from the completion of vacuum infusion and the peak of resin exothermic heat, the corner position of the blunt tail edge of the first three blades made on mold 1# and 2# respectively was not treated, and only the highest temperature of the curing process in the corner area was recorded; The corner temperature of the blunt tail edge of the last three blades made on the 1# and 2# molds was monitored in real time, and when the temperature increased sharply, the corner position was cooled by spraying water from a watering can or wiping with a wet rag (as shown in Fig. 10), and the highest temperature in the curing process of the corner area was recorded (as shown in *Table 3*).

Table 3

Temperature record data

Unit: °C

Location / Group number	Location1 6m	Location2 10m	Location3 14m	Location4 18m
1#-1	112	108	109	115
1#-2	107	114	113	106
1#-3	105	103	111	99
1#-4	75	77	84	79
1#-5	78	86	79	81
1#-6	76	83	81	80
2#-1	93	90	86	87
2#-2	86	92	91	90
2#-3	87	90	84	91
2#-4	72	70	68	65
2#-5	70	69	66	68
2#-6	69	67	72	65

Fig. 10 Corner cooling operation

Finally, after the curing, remove the auxiliary material on the corner surface of the blunt trailing edge, judge the defect in the corner position of the blunt trailing edge, and polish the corner position to observe the internal situation of the defect (as shown in Fig. 11).

Fig. 11 Schematic diagram of defect grinding

Defect standard:

a. Severe whitening: refers to the incompletely infiltrated glass fiber cloth layer number of ⩾5;

b. Slight whiteness: refers to the number of layers of glass fiber cloth with incomplete infiltration ⩽5 layers.

3.3.1 Test result

Through the laying of the blunt tail edge corner area, the maximum temperature statistics of the curing process and the apparent results of the curing molding are as follows:

Table 4

Result statistics

Group number	Is there a gap?	Whether the cooling	The results
1#1	Yes	No	Serious white (See Figure 12)
1#2			
1#3			
1#4		Yes	Mild white (See Figure 14)
1#5			
1#6			
2#1	No	No	Mild white (See Figure 13)
2#2			
2#3			
2#4		Yes	There is no white (See Figure 15)
2#5			
2#6			

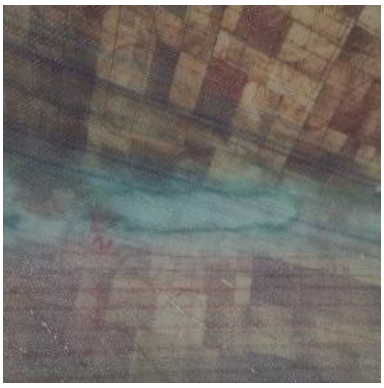

Fig. 12 No cooling, corner gap

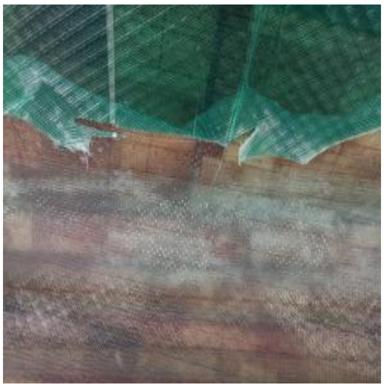

Fig. 13 No cooling, no clearance in corner

Fig. 14 Cooling, corner gap

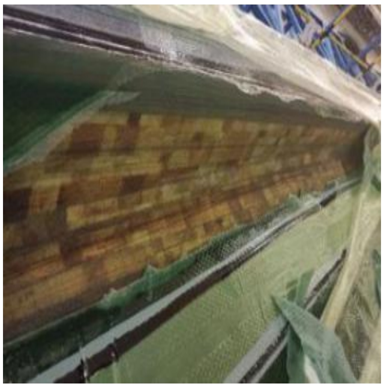

Fig. 15 Cooling, no clearance in corner

a. As shown in Fig. 12, there is a gap in the corner area, and the highest curing temperature of the blade without cooling measures is between 99℃ and 115℃, and the corner area is seriously white. After polishing the white area, it is found that there is a certain resin rich phenomenon.

b. As shown in Fig. 14, there is a gap in the corner area, and the highest curing temperature of the blades that take cooling measures during curing is between 75℃ and 86℃, and the corner area is slightly white. After polishing the white area, it is found that there is a certain phenomenon of rich resin

c. As shown in Fig. 13: there is no gap in the corner area, and the highest curing temperature of the blade without cooling measures is between 84℃ and 93℃, and the corner area is slightly white. After polishing the white area, it is found that there is no resin rich phenomenon.

d. As shown in Fig. 15, there is no gap in the corner area, and the highest curing temperature of the leaves that take cooling measures in the curing process is between 65℃ and 72℃. There is no whitening in the corner area, and there is no resin rich phenomenon.

4. Analysis of the test results of blunt tail edge corner whitening inducement test

4.1. Analysis of the effect of perfusion resin bubbles on whitish at the corner of blunt tail edge

The resin bubble perfusion on leaves has a great influence on the forming of leaves, especially the corner area of blunt trailing edge. The resin with good defoaming effect has a good curing effect on the surface after the resin is perfused and formed, and there is no whitening and other infiltration defects. The effect of defoaming is poor or the resin without defoaming is poor after perfusion molding. The corner area in the blunt trailing edge of leaves is more likely to produce white, bubble aggregation and other infiltrating defects. It is suggested that epoxy resin should be treated with single-component or two-component defoaming respectively in the process of leaf production. If production conditions permit, it is recommended to use the online all-in-one machine for perfusion of all blade components. The online all-in-one machine has the advantages of good defoaming effect and automatic control of resin flow. The resin flows directly into each blade component through the pipe from the online all-in-one machine, preventing the resin from contacting the air.

4.2. Analysis of the effect of core material moisture content on whitish corner of blunt tail edge

When the moisture content of the core material reaches 1.3%~1.5%, the water and the resin combine and react during the curing process of the leaf, leading to the occurrence of the resin explosion and whitening defect. Therefore, when laying Balsa wood core material in the process of making leaves, the moisture content of Balsa wood in the corner area of blunt trailing edge should be controlled, which can effectively reduce the whitening defect in the corner area of blunt trailing edge of leaves and improve the quality of leaf products.

4.3. Analysis of the effect of ply structure on the whitening of blunt tail edge corners

By comparing and testing 76A(LZ) and 76(LZ) bladed trailing edge structures, it is concluded that if the corner structure layer of blunt tail edge is all covered with glass fiber cloth layer, when cooling measures are taken during the vacuum perfusion process, there will be no whitening defects in the corner area. If the corner structure layer of the blunt tail edge is laid with an inner and outer glass fiber cloth layer, and the core material structure is contained in the middle, the gap between the cloth layer and the core material and the high temperature of curing occur in the production process, which will lead to white defects in the corner of the blunt tail edge. By refining the operation instructions of the corner area, standardize the operation mode of employees, ensure that there is no gap in the corner area, and effectively reduce the white defect of the blunt tail edge corner caused by the gap of the layer; At the same time, in the curing process, cooling measures are taken to avoid high temperature in the corner, which can effectively reduce the white defect of the blunt end edge corner caused by high temperature.

5. Conclusions

Fan blade is one of the key parts of wind turbine, which is related to the safety and stability of wind turbine operation. Its quality problem has been paid more and more attention. In this article, through the test and blade track and analyze the process of production, expounds the influence of blade blunt trailing edge corner of the main causes of white, by controlling the bubble content, core material moisture content in resin, and blunt trailing edge corner structure layer laying effect and related factors such as curing temperature, can effectively reduce or even eliminate blade whitish blunt trailing edge corner defects, improve the quality of products, Provide reliable quality guarantee for the safe and stable operation of wind motor group leader cycle[14]. Of course, there are various causes for the corner whitening of blunt trailing edge, which are affected by many factors such as working conditions and material characteristics. This paper will not elaborate on it for the moment, and further test verification and analysis will be conducted on other causes in the future.

Acknowledgement

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