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PROCESS RESEARCH AND OPTIMINZATION OF PINHOLE HOLE AND NAIL HEAD DAMAGE ON COMPOSITE PARTS

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Abstract

Advanced composite materials are widely used in modern aircrafts due to their advantages of low specific gravity, high strength, and good fatigue performance. The composite winglet surface components that use composite material skin as the aerodynamic profile surface put forward higher requirements on the surface quality of the product. The composite material small wing surface component assembly specializes in the integration of cold process assembly and hot process assembly. During the assembly process, the components undergo a cold process assembly and a hot process assembly. There are two common quality problems on the surface, namely, the surface pinhole holes and nail head grinding damage caused by the flame spraying of aluminum on the parts. This paper verifies the formation mechanism of pinhole holes through process research. And by adjusting the process, optimizing the process and other methods, a new set of process methods for mixing, coating, and not needing to polish the adhesive can also meet the surface quality requirements of the aviation industry. It greatly reduces the occurrence of pinhole hole failures, and eliminates nail head grinding damage failures from the root cause, and provides a theoretical basis for automatic gluing technology.

Keywords: Aviation assembly, composite parts, pinhole holes, nail damage, surface quality

1. General Introduction

One of the signs of the advancement of new aerospace vehicles is the advancement of the structure, and advanced composite materials are an important material basis and leading technology to realize the advancement of the structure[1].Composite material refers to a new type of material composed of several different types of materials, such as organic polymers, inorganic non-metals, or metals[2].Advanced composite materials (ACM) mainly refer to resin-based composite materials reinforced with high-performance fibers (such as boron fibers, carbon fibers, and aramid fibers)[3].Carbon Fiber Reinforced Polymer/Plastic (CFRP) is the most representative, most widely used and most important advanced composite material[4].

With the maturity of material technology and the improvement of product quality, the proportion of high-performance composite materials used in the aerospace field has greatly increased[5].The amount of composite materials used in the Boeing 787 Dreamliner has reached 50% of the structural mass[6].Composite materials have shown a tendency to become the main material of large-scale civil aircraft structures.Transport aircraft, helicopters, unmanned aerial vehicles, general aviation aircraft and aerospace vehicles also use a large number of composite structures, and even fully composite structures.The amount and application level of composite materials have become an important indicator of the advancement of aircraft[7].

The skin part is a thin plate that constitutes the aerodynamic shape of the aircraft, and is also the covering part of the internal structural frame of the aircraft[8].The skin parts cover the outer surface of the aircraft and directly contact the airflow during flight to generate friction[9].Its surface quality has a great influence on the appearance, aerodynamic performance, service life, cruising speed, fuel consumption and stealth performance of the aircraft.Because the composite material is equivalent to aluminum alloy in comprehensive performance, but the specific stiffness and specific strength are higher than aluminum alloy[10]， and it has the advantages of high temperature resistance, fatigue resistance, good damping and shock absorption, and performance can be designed[11],composite skins have gradually replaced metal skins, and have achieved important applications in modern aircraft wing parts.The composite material small wing surface component assembly specializes in the combination of cold process assembly and hot process assembly. The tolerance distribution in the two assembly processes penetrates and influences each other, which poses higher challenges to assembly technology in terms of assembly structure design and assembly process optimization.The problem of pinhole holes on the surface of composite parts and nail head damage is a typical composite material assembly quality problem.

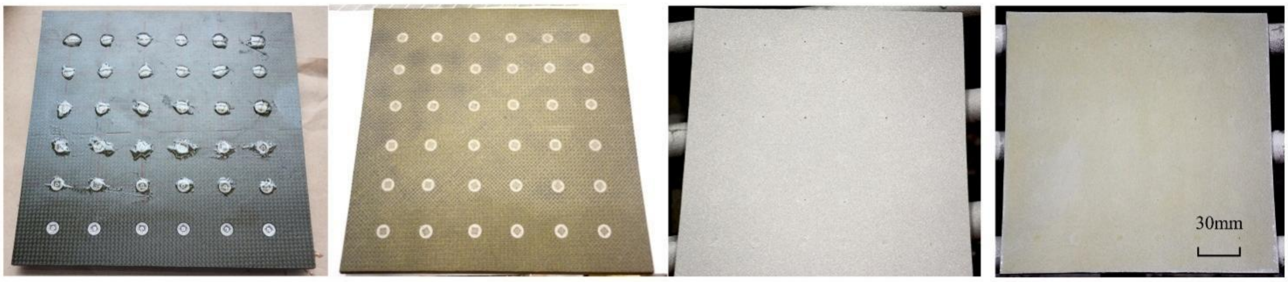
In this paper, a series of experiments are conducted to study the formation mechanism of pinhole holes on the surface of composite parts. A new set of process methods for mixing glue, applying glue, and without grinding the adhesive, can meet the surface quality requirements of the aviation industry. Greatly reduce the occurrence of pinhole hole failure, and prevent nail head grinding damage from the root cause.

2. Cause exploration

2.1 Experimental materials and conditions

This experiment selects 200×200×5.6mm carbon fiber reinforced resin matrix composite material board. The nailing grade is XXX2312-06-250, and the nail position distance is 30mm. DG-3 room temperature curing epoxy adhesive is used to fill the nail head. The flame sprayed aluminum coating resistance is Class I, with a resistance value of 0.5 to 1.3 mΩ (equivalent to a coating thickness of 0.1 mm). The sealing glue is formulated with "XC-1" diluent, and the viscosity is measured in the range of 11-12 seconds with a "tu-4" cup. After the sealing glue is applied by brushing, leave it in the air at 18~30℃ for 12 hours, then enter the oven at 60±5℃ for 13 hours for curing.

According to the traditional gluing method, in order to ensure the surface quality of the parts at the nail head, and at the same time meet the requirements of nail head sealing, the nail head on the surface of the parts after the riveting connection needs to go through the following processes:nail head interference gluing, adhesive curing, polishing adhesive, sand blowing, flame spraying aluminum, sealing glue curing, grinding and sealing glue, needle hole rework, repair glue curing and grinding, etc. The changes of the test board in different processes Figure 1.

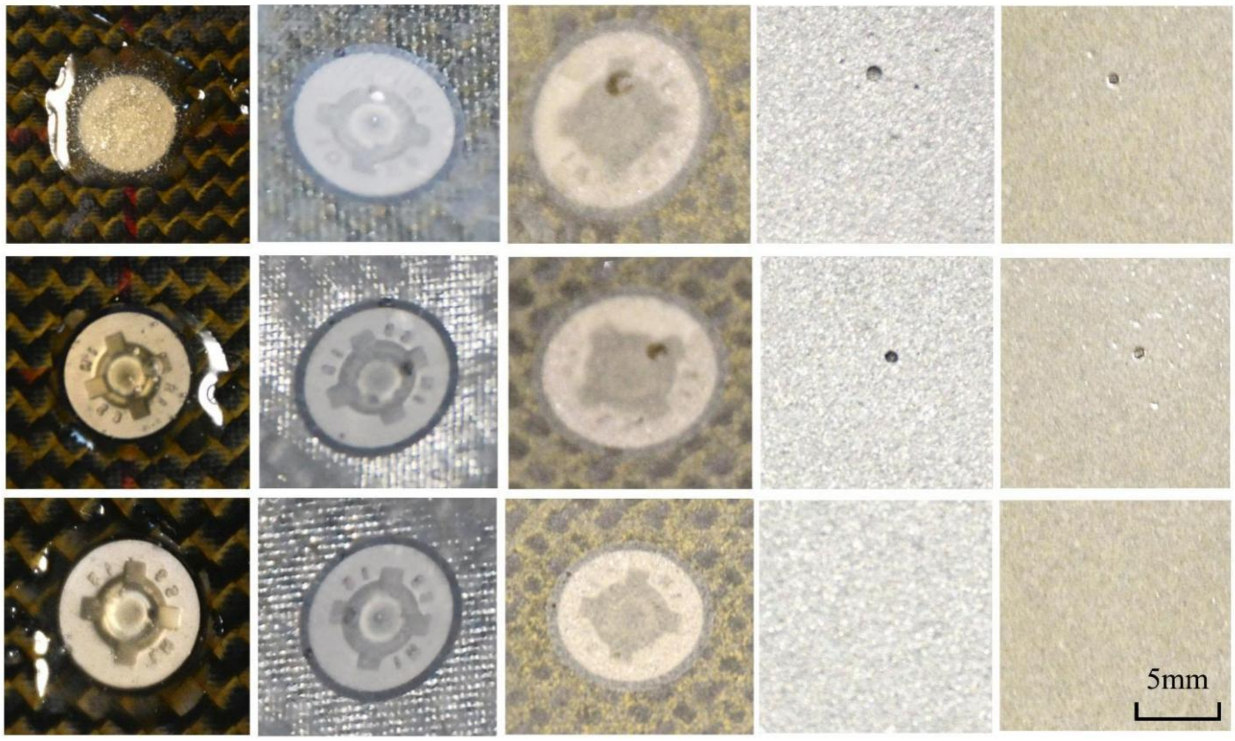


(a) Interference coating (b) Sand blowing (c) Flame sprayed aluminum (d) Sealing glue

Figure 1 – Changes of the experiment board in different processes

2.2 Control experiment

This paper designs three groups of control groups: turbid glue, clear bubble-containing glue, and clear bubble-free glue. Track the evolution of the surface quality of the fixed position of the test piece. Explore the evolution mechanism of air bubbles in the nail groove during the process of forming pinhole holes during interference coating, polishing adhesive, sand blowing, flame spraying aluminum, and sealing and curing, as shown in Figure 3.

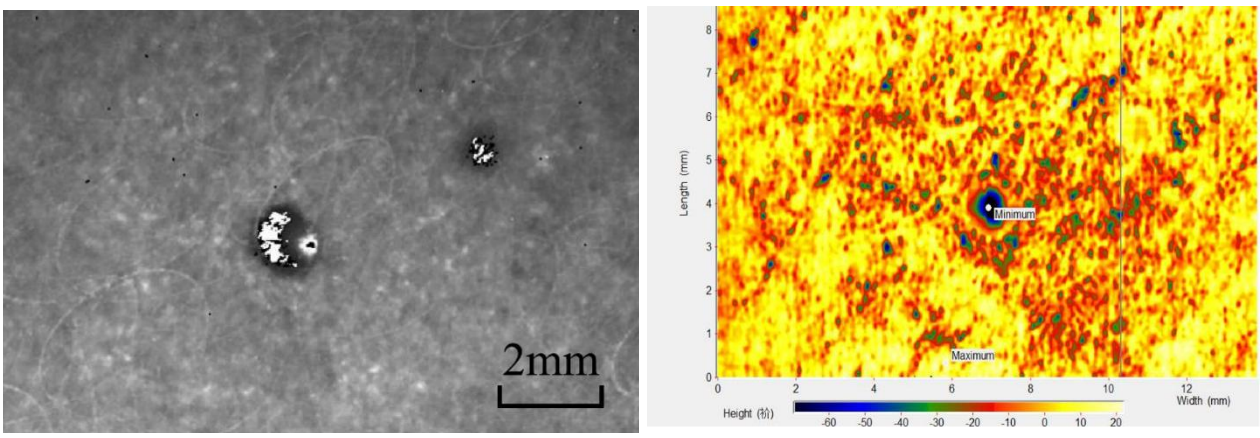


(a) Interference coating (b) Polished (c) Sand blowing (d) Flame sprayed aluminum (e) Sealing glue
Figure 2 – Comparison of the evolution of the surface quality of a single pull nail

2.3 Experimental results and analysis

Experimental conclusion: It is confirmed that the pinhole holes in the nail connection area on the surface of the component are evolved from the air bubbles attached to the nail groove during the glue application process.

DG-3 room temperature curing epoxy adhesive is a high-viscosity adhesive. Its component A has a viscosity of 100~300Pa · s, and its component B has a viscosity of 3~15Pa · s. The traditional process method is: weigh the two components of A and B according to a certain mass ratio, and manually mix and adjust the glue. A large number of bubbles are mixed in the glue during the mixing process, the glue is turbid, and the viscosity is relatively high. After the nail head is glued, it is impossible to judge whether there are bubbles in the groove, so that the fault cannot be detected at the source, and it gradually becomes prominent in the subsequent process. At this time, the specific performance is: the silver-gray part surface after spraying aluminum has a circular black hole with a diameter of about 0.6~1.6mm, which is slightly sunken, which is widely present in the concentrated area of the nail head. Using a three-dimensional optical surface measuring instrument, the average depth of the circular black hole is 90.6μm, as shown in Figure 3.



(b) Gray micrograph (b) Color micrograph

Figure 3 – 3D optical surface measurement photo of pinhole hole

In addition, in order to ensure the surface quality of the parts, the nail head gluing process often adopts interference gluing, and the surface is polished after the adhesive is cured. The nail head is easily damaged during the polishing process, as shown in Figure 4.

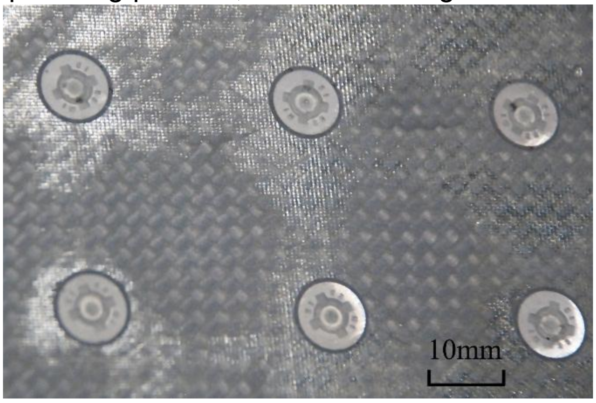


Figure 4 – Nail head damage during sanding of adhesive

3. Process Optimization

3.1 Static mixer mixing

The traditional DG-3 adhesive mixing method is: according to a certain mass ratio, manually weigh the two components of A and B, and mix and stir until uniform. During the mixing process, a large number of bubbles are mixed in the glue liquid, showing a turbid milky yellow characteristic. The new scheme selects the mechanical glue mixing method, and the two components of A and B that meet the quality ratio requirements are mixed in a static mixer, and finally a light yellow clear glue without bubbles is obtained (Figure 5).

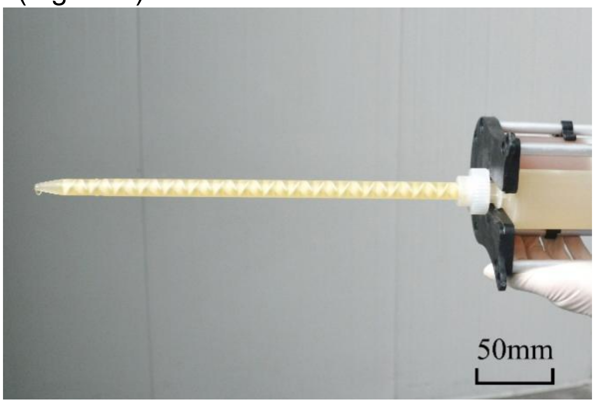


Figure 5 – Static mixer mixing

3.2 Process plan optimization

The new process plan has improved the traditional nail head interference coating and solidified adhesive polishing process methods, including: dipping in a bubble-free clear glue solution for dispensing to ensure that there are no visible bubbles in the groove area of the nail head; Then adopt a new glue squeegee method to form a smooth transition between the glued area and the surface of the composite part; cancel the process of polishing the adhesive, and directly perform the processes of sand blowing and flame spraying of aluminum (Figure 6 and Figure 7).

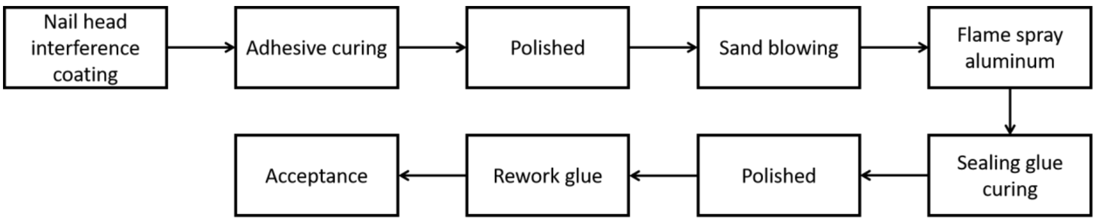


Figure 6 – Traditional process

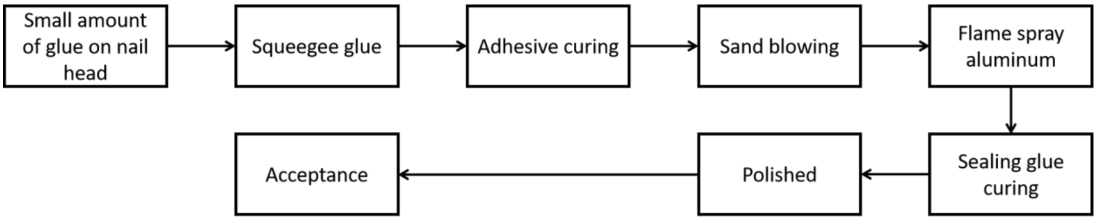


Figure 7 – New process

Due to the shrinkage phenomenon of the cured DG-3 adhesive on the surface of the parts using the new process method, the nail head groove area appears slightly sag. During the curing process of the sealing glue, there will be slight glue accumulation (Figure 8). The average depth of the groove is 37.7μm. After the adhesive is cured, a patching and re-curing process can be added to obtain almost flawless surface quality.

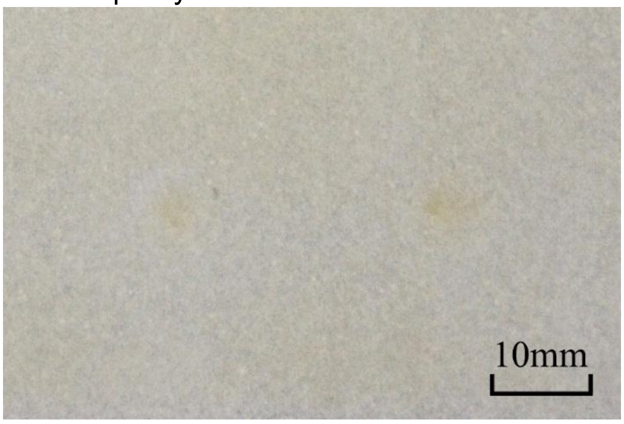


Figure 8 – Glue accumulation phenomenon

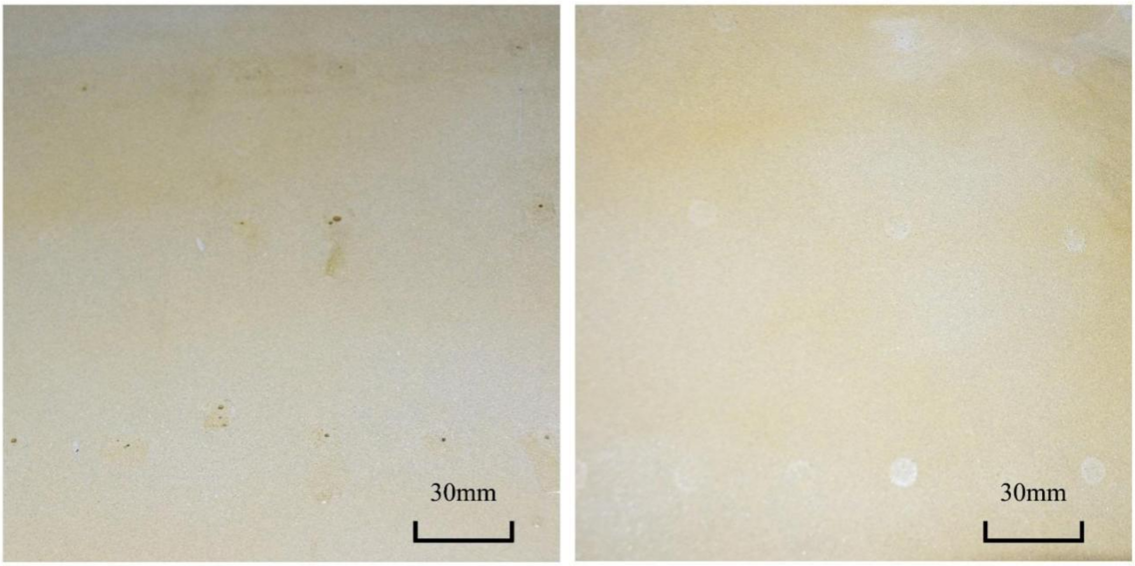
3.3 Application effect

In this paper, the porosity η is used as an index to measure the occurrence probability of pinhole holes on the surface of composite material parts. The calculation formula of η is:

$$\eta = \frac{m}{n} \times 100\% \quad (1)$$

Where n is the number of nail connectors on each small wing surface composite component, and m is the number of pinhole holes with a surface greater than 0.6mm when the component is finally delivered.

The pinhole hole rate of the composite material surface before adopting the new process reaches 80%~120%, as shown in Figure 9(a). After adopting the new process scheme, the pinhole hole rate is reduced to below 5% or even 0, and the entire surface is smooth and without black spots, as shown in Figure 9(b). And because the process of polishing the adhesive is eliminated, the hidden quality hazards of nail head damage and nail head coating damage are completely eliminated, and the aerodynamic performance, safety and stability of composite parts are improved.



(a) Traditional method (b) new method

Figure 9 – Comparison of surface quality of composite parts

4. Conclusions

- The root cause of the pinhole holes on the surface of composite parts is the air bubbles that remain in the nail groove during the nail head gluing process. After curing, grinding, sand blowing, flame spraying aluminum and other processes, it evolved into a circular black hole with a diameter of about 0.6 to 1.6 mm and a slight depression.
- In the new process plan, the use of mechanical glue mixing to obtain a bubble-free clear glue, the original dot coating method avoids the adhesive grinding process, and effectively avoids pinhole holes and damage to the nail head. Improve the surface quality of parts and ensure the safety of aviation products.

Copyright Statement

References

[1] Du Shanyi.Advanced composite materials and aerospace[J].Journal of Composite Materials,2007(01):1-12.

[2] Shi Changxu. A Great Dictionary of Materials[M]. Chemical Industry Press, 1994.

[3] Du Shanyi, Guan Zhidong. Thoughts on the countermeasures of advanced composite technology for large passenger aircraft in my country[J]. Journal of Composite Materials, 2008, 25(1):5-5.

[4] Wang Hua.The research status and development trend of aircraft advanced composite material structure assembly coordination technology[J].Aviation Manufacturing Technology,2018,61(07):26-33.

[5] Ma Baoquan,Zhou Zhengqian.Progress and development trend of non-contact and non-destructive testing technology for aerospace composite structures[J].Acta Aeronautica Sinica,2014,35(07):1787-1803.

[6] Chen Shaojie. Composite Material Technology and Large Aircraft[J]. Acta Aeronautica Sinica, 2008, 29(3):605-610.

[7] Gu Yizhuo,Li Min,Li Yanxia,Wang Shaokai,Zhang Zuoguang.Progress in manufacturing technology and process theory of composite materials for aircraft structure[J].Acta Aeronautica Sinica,2015,36(08):2773-2797.

[8] Wang Xiaoxin,Zeng Yipan,Chen Lin,Dong Jinliang.Analysis and optimization of stretch forming process for skin parts with complex curvature[J].Forging Technology,2018(09):88-92.

[9] Editor-in-Chief of "Manual of Aviation Manufacturing Engineering". Manual of Aviation Manufacturing Engineering[M]. Aviation Industry Press, 1997.

[10] Mair R I. Advanced composite structures research in Australia[J]. Composite Structures, 2002, 57(1–4):3-10.

[11] Du Shanyi.Advanced composite materials and aerospace[J].Journal of Composite Materials,2007(01):1-12.