Research on Design of Lightweight-Blade Metro Fan Based on Glass Fiber and Phenolic Resin Composite

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Abstract. With the development of urban construction and the continuous increase of subway operating mileage, the energy consumption of subway ventilation system has become a hot spot of concern. For the subway fan, a lightweight blade subway fan design based on glass fiber phenolic resin composite material is proposed. It has the advantages of low cost, high strength, and good energy-saving effect. It is an effective way of light-weight and energy-saving subway fans.

Keywords: Glass fiber, phenolic resin, composite material, blade.

1. Introduction
With the further acceleration of my country's urbanization process, traffic pressure in large cities continues to increase, and subway construction is developing rapidly. With the continuous increase of subway operating mileage, the problem of excessive energy consumption has gradually attracted widespread attention. Among them, the subway ventilation system is an important part of the subway system. The energy consumption of the subway ventilation system can reach 50% of the total energy consumption of the subway system. The subway fans must run for up to 20 hours a day. The efficiency of subway fans has attracted the attention of scholars at home and abroad, but the research and application of composite blades in subway fans are few.

This paper proposes a research and design plan for a lightweight-blade subway fan based on glass fiber phenolic resin composite material, which comprehensively considers factors such as lightweight, high temperature resistance and cost, and carries out structural design, material design, and layer design for composite fan blades. And use finite element simulation analysis to study the statics performance of composite blades. This research is an effective way to solve the problem of light weight and energy saving of subway fans, and it has great engineering research and application value.

2. Overall scheme design
This paper designs a lightweight-blade subway fan based on glass fiber phenolic resin composite material. By preparing glass fiber phenolic resin and aluminum alloy composite material, the blade is manufactured by one-time mold forming, reducing the number of parts and joints. Fasteners have the advantages of low cost, small starting inertia, good impact absorption, unique explosion-proof performance, and good energy-saving effect.

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3. Composite material design

3.1. Composite material design requirements

The basic starting point in the application of fiber-reinforced composite materials is to have the characteristics of high specific strength and high specific stiffness [1]. The higher the specific strength and specific modulus, the lighter the quality of the structure. There is also the anisotropy of FRP mechanical properties. Through reasonable design, the bearing capacity of the material can be maximized, and the lightweight structure design of composite materials can be achieved. The phenolic resin matrix has strong cohesion after curing and crosslinking, so it has excellent mechanical properties.

Compared with metal materials, such as aluminum alloy, titanium alloy and structural steel, fiber reinforced composite materials, such as glass fiber composite materials, carbon fiber composite materials, have the advantages of light weight, high specific strength, strong corrosion resistance and good fatigue resistance. Moreover, the composite blade can be formed by a mold at one time, which reduces the number of parts, and has a smooth surface, accurate structure and size, and easy maintenance.

The first stage optimizes the size of the composite material to determine the required structure, the second stage gives a thickness optimization design plan, and the third stage performs multiple stacking optimizations based on the anisotropy and strong designability of the composite material. In addition, sandwich structures, grid structures, truss structures, and metal materials can also be used to improve the performance of strength and rigidity [2], using ABAQUS finite element software simulation and experiment to reveal interlayer damage, fiber damage and matrix the evolution process of damage [3]. For the buckling optimization design of the composite grid structure, based on the parameterized design and optimization design of the finite element model, the optimal curved grid pattern is found and evaluated through buckling analysis.

3.2. Analysis of composite material properties

Compared with carbon fiber, glass fiber is electrically neutral [4], there is no potential corrosion, the elongation and thermal expansion coefficient are large, and the curing residual stress is small. Therefore, the composite of glass fiber composite material and aluminum alloy is an ideal material. The tensile properties of the glass fiber composite material-aluminum alloy meet the metal volume fraction theory, which can provide a theoretical basis for the performance calculation of the glass fiber composite material-aluminum alloy composite material.

In terms of resistance to temperature and humidity [5], due to the protection of the outer metal layer, the fiber metal layer can always absorb moisture generated by distilled water or salt spray, reducing its damage to the fiber layer of the metal layer. Glass fiber phenolic resin composite material—aluminum alloy composite material has superior flame retardant performance. The single-sided flame burn-through results at 2500°C show that when the thickness of the aluminum layer of the laminate is 0.2-0.3mm, the glass fiber phenolic resin composite material—aluminum alloy the burn-through time of composite laminates is dozens of times that of 1mm thick aluminum alloy plates. The reason is: the outermost aluminum plate of the glass fiber phenolic resin composite material-aluminum alloy composite laminate melts rapidly (melting temperature is 500°C), but the carbonization time of the inner fiber resin layer is relatively slow [6], this is because the glass fiber the melting point is relatively high, which can prevent flames from penetrating through the glass fiber phenolic resin composite-aluminum alloy composite laminate. In addition, the thermal expansion coefficients of each component (aluminum alloy sheet, glass fiber, resin) of the glass fiber phenolic resin composite material-aluminum alloy composite laminate are different, which will lead to the glass fiber phenolic resin composite material—aluminum alloy composite laminate Heat stratified and form an air layer that isolates heat.
In terms of weight reduction, the current main material used for subway fan blades is aluminum alloy, while composite fan blades have excellent performance. Composite materials are an effective way to reduce product weight. Compared with the performance requirements of civil aviation engine fan blades, subway fan blades are used the performance is far lower, and it is necessary to design and study composite fan blades that meet the requirements of subways. There are few cases and studies on composite fan blades for subways at home and abroad.

Subway fan blades should have high temperature resistance, that is, when installed in the station ventilation and smoke exhaust system, the fan must be able to work continuously for 1h when the medium passes through 250℃ and 0.5h when the medium passes through 280℃. It is installed in the tunnel ventilation and smoke exhaust system. It can work continuously at 150℃ for 1h. Composite materials will decrease structural mechanical properties at high temperatures. This device uses glass fiber composite materials and metal alloy composite technologies to solve the application problem of composite materials in subway fans.

3.3. Composite material process route

The preparation process of the glass fiber phenolic resin composite material-aluminum alloy composite material is shown in the figure. It first includes the surface treatment of the metal sheet and the preparation of the prepreg, and then it is laminated and cured by heat and pressure to form the final shape. The surface treatment of the aluminum alloy needs to go through acid washing, alkali washing, decontamination and anodization (usually phosphoric acid or chromic acid anodization is used to produce a uniform and dense oxide film on the surface, which increases the surface roughness. Adhesive performance), and then need to spray primer within 24 hours (two functions, one is to prevent the dense cavity structure of the aluminum alloy plate from oxidizing in the air, and the other is to form a resin-rich area between the aluminum alloy and the prepreg to improve the adhesion Effect). Lay the dried aluminum alloy and glass fiber phenolic resin prepreg in order according to the design, and put it in a vacuum bag with other replication materials, and then seal, exhaust, heat and press to cure. The preparation process of glass fiber phenolic resin composite material-aluminum alloy composite material is shown in Figure 1.

**Figure 1.** The preparation process of glass fiber phenolic resin composite material-aluminum alloy composite material
3.4. Composite material experimental data analysis
In this experiment, the materials are divided into four categories, denoted as A, B, C, and D. There are 10 types of A materials, denoted as A1-A10; 6 types of B materials, denoted as B1-B3, B6-B8; 6 types of C materials, denoted as C1-C3, C6-C8; Type D there are 6 kinds of materials, denoted as D1-D3 and D6-D8. The shape of the curve obtained during the tensile test for each material is roughly the same. The following figure takes the A10 material as an example for data analysis. The relationship between the displacement of the A10 material and the external force applied to the material during stretching is shown in Figure 2.

![Figure 2. A10 material stretch curve](image)

The longitudinal displacement of the material increases with the increase of the applied external force. According to the data obtained by the experimental machine, when the applied external force reaches 33.199kN, the material reaches the local deformation stage and the material is broken. Compared with the current aluminum alloy blades, this material has higher tensile strength and meets the requirements of the working environment of the device.

Realize the scene photos as shown in Figure 3:

![Figure 3. Experimental equipment and experimental materials](image)

4. Research methods and technical routes

4.1. research method
In the research of this project, a research method combining theory and numerical simulation, experimental design and experimental testing is adopted. The composite fan blades are designed through
theoretical design and numerical simulation, and the data from experimental tests are mutually verified to obtain the feasibility of composite subway fan blades. Sexual analysis.

Theory and simulation method: Use composite material structural mechanics and structural design theory to carry out static simulation of composite material fan blades, and then determine the design scheme for modal simulation.

Experimental test method: the strength and rigidity test of composite material subway fan blades.

### 4.2. Technical route

The technical route of the research of this device is as follows: first, carry out theoretical calculations related to composite material subway fan blades, and then carry out the overall design of subway fan blade composite materials after a certain theoretical basis, and then establish a finite element model of composite material subway fan blades. Perform statics simulation on the model of, if it does not meet the requirements, perform the finite element model optimization design until the simulation results meet the requirements, and then perform modal simulation and sample preparation for the device that meets the requirements. After completing the sample preparation, perform experimental tests to verify the results. The technical route is shown in Figure 4.

![Figure 4. Technical route](image)
5. Conclusion
This scheme designs lightweight subway fan materials, which has the advantages of light weight, high temperature resistance and high-cost performance. The lightweight fan blades are composite material blades, which can be formed and manufactured by molds at one time, which facilitates the realization of fully automated production and provides support for subsequent mass production and standardized production of lightweight fans.

Lightweight fan blades also have the advantage of high temperature resistance. They can work stably and continuously under a working fluid environment of 250°C. They can be applied to the high-temperature exhaust gas discharge system of large-scale exhaust gas plants, such as thermal power plants, gas plants, etc. It can also be combined with exhaust gas turbocharging technology and exhaust gas recirculation technology to be used in exhaust systems that use waste heat for power generation, such as: exhaust gas from external air conditioners in large factories, exhaust gas from large engines, etc. It is necessary to provide a stable heat source for waste heat recovery Utilized high-temperature exhaust gas utilization system.

At the same time, the fan blades have the advantages of low starting inertia and fire protection, and can be used in anti-corrosion and explosion-proof situations, such as the exhaust system of underground coal mining areas and underground natural gas mining areas. Lightweight fan blades have the advantage of reducing wind resistance, can improve exhaust efficiency, and meet the exhaust requirements of large exhaust plants such as thermal power plants and steel plants.

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