

Pyrolysis-recycling Utilization Properties Waste Wind Turbine Composite Blades

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Abstract. As a clean and environmentally friendly energy, wind energy is developing rapidly. With the development and construction of wind farms, wind turbines have reached their service life in succession and entered the stage of decommissioning. In this paper, the typical waste glass fiber reinforced epoxy resin composites wind turbine blades are studied and discussed, and the mechanical tensile properties and surface micro properties are analyzed. The tensile strength of blade materials pyrolysis residue was measured by universal testing machine, and the pyrolysis experimental residue of blade materials were characterized by SEM, the change law of micro morphology of blade samples in pyrolysis process were analyzed. The results show that when the pyrolysis temperature is 350.0 °C, the loss rate of elastic modulus of pyrolysis residue of blade materials at this temperature is low, and the pyrolysis residue with good elastic modulus and tensile strength can be recovered.

Keywords: Waste wind turbine blade; Pyrolysis; Recycling; Glass fiber reinforced epoxy resin; Mechanical properties.

1. Introduction

In recent years, with the excessive consumption of fossil energy and its serious impact on the environment, wind energy has attracted more and more attention due to its environmental protection, cleanliness, recyclability and many other advantages, and is the most potential emerging energy [1, 2]. Wind turbines, as equipment for the effective utilization of wind energy, have their installed capacity increasing year by year. Statistics showed that the global market added 77.6 GW of installed capacity in 2022, and the cumulative installed capacity reached 906.0 GW. However, with the rapid development of global wind energy, early wind turbine blades will face aging and decommissioning in the next few years. In 2022, 59,000 tons of decommissioned wind turbine blades will be produced. By 2030, the total annual amount of discarded wind turbine blades in the world is expected to reach 40 million. 10,000 tons, the generation of a large number of waste wind turbine blades will raise concerns about environmental problems. The main material of the blade materials are reinforced fiber (glass fiber reinforced epoxy resin) thermosetting resin matrix composite materials [3-5]. Glass fiber reinforced polymer (GFRP) is the most commonly used material for wind turbine blades due to its light weight, high strength, excellent mechanical strength and fatigue resistance [6]. However, this material is made through a cross-linking reaction, cannot be remelted or reshaped, is difficult to recycle, and is resistant to corrosion and cannot be naturally degraded. Only by effectively treating it can long-term pollution to the environment be avoided. and destruction for sustainable development [7-10].

At present, there are few studies on the pyrolysis recovery characteristics of glass fiber reinforced epoxy resin composites fan blade materials, and there is a relatively lack of research on the evaluation of mechanical properties of waste wind turbine blades after pyrolysis. Zhang Ying [11] used a thermogravimetric-differential thermal synchronous analyzer to study the pyrolysis characteristics of typical high-strength glass fiber/epoxy resin composites under the influence of different heating rates and different atmospheres, then using Kissinger method and Flynn-Wall-Ozawa method, the apparent activation energy of each transformant during pyrolysis was obtained. Shi and Bao [12] studied the effects of pyrolysis time and temperature on recycled

glass fiber reinforced plastics, and discussed their optimal decomposition conditions for superheated steam.

This paper adopts the pyrolysis recovery method that is most likely to achieve commercial operation at present to recycle the waste wind turbine blades, focusing on "essential greening". By studying the degradation law of solid residues under different final pyrolysis temperatures and residence times. The mechanical properties of pyrolysis residues and the possibility of fiber recycling were discussed in order to provide a basic reference for the industrialized continuous pyrolysis incineration and safe disposal of waste wind turbine blades.

2. Experiments

2.1 Materials

The test samples of glass fiber reinforced epoxy resin composite material (glass fiber reinforced plastic) type wind turbine blades, produced by Shandong Grad Group Co., Ltd. (Dezhou, China).

2.2 Experimental

2.2.1 Mechanical property analysis

The mechanical property analysis is divided into pyrolysis experiment and mechanical property measurement experiment. The pyrolysis experiment was measured on a tube furnace pyrolysis experimental bench device. The holding time was uniformly 30 min in the nitrogen atmosphere with a pressure of 0.2 MPa and an air flow rate of 0.5 L/min. The final temperature of solution (350.0, 450.0 and 550.0 °C), and the heating rate of the tube furnace was controlled at 10 K/min. Determination of mechanical properties The experiment was carried out on the Meister CMT6103 universal testing machine, and the pyrolysis residue was subjected to a tensile test. The parameters were set as the gripping distance of 12 mm, the tensile rate of 0.05 mm/min, and the maximum tensile force of 5000 N and the tensile strength, elongation at break, tensile modulus were obtained.

2.2.2 Surface micro property analysis

Surface microscopic properties analysis were conducted on a SU8010 scanning electron microscope (SEM; Hitachi, Japan). The block samples after the combustion of the waste wind turbine blade materials are selected, and the sample size is less than 10 mm in length and width, and less than 10 mm in thickness. The blade samples were tested after gold spraying treatment, the original blade samples were selected at 1 K, 5 K and 20 K magnifications. After the thermal mass loss experiment, the blade samples were selected at 5 K and 20 K. After the pyrolysis experiment, the blade samples were selected at 1 K, 5 K and 20 K magnification.

3. Result and discussion

3.1 Tensile properties at different final pyrolysis temperatures

Due to the difference in the completion degree of the pyrolysis reaction of waste wind turbine blades at different final pyrolysis temperatures, there are significant differences in the internal chemical composition of each sample when it reaches the final pyrolysis temperature which in turn results in significant differences in the mechanical properties of each sample. The comparative analysis data shows that with the increase of the final pyrolysis temperature, the elastic modulus and tensile strength show a trend of first decreasing and then increasing, while the elongation at break shows a trend of increasing first and then decreasing. Table 1 shows the mechanical properties of the samples at different final pyrolysis temperatures.

Table 1. Mechanical properties of different final pyrolysis temperatures.

Final pyrolysis temperature (°C)	Elastic Modulus (MPa)	Tensile Strength (MPa)	Elongation at break (%)
350.0	315.72	10.51	14.62
450.0	114.26	2.59	34.21
550.0	180.06	2.78	10.24

The glass fiber epoxy resin composite blade materials will reach the peak of thermal decomposition rate between 390.0 °C-410.0 °C in the nitrogen atmosphere, in which the epoxy resin undergo thermal decomposition reaction, the structure is damaged, the internal chemical composition of blade samples change, and the mechanical properties of blade materials change. When the final pyrolysis temperature is 350.0 °C, a small amount of epoxy resin decomposes. At this stage, the main part of the pyrolysis residue of blade material is still epoxy resin and glass fiber. At this time, the mechanical properties of the pyrolysis residue are basically characterized by the mechanical properties of glass fiber epoxy resin composite. The experiment under the final pyrolysis temperature provides the possibility for the resource recovery and utilization of the composite components of waste wind turbine blades. When the final pyrolysis temperature is 450.0 °C, most of the epoxy resin decomposes and the glass fiber hardly decomposes. At this stage, the main part of the pyrolysis residue of the blade samples are glass fiber. The ash after the thermal decomposition of the epoxy resin is attached near the glass fiber, and the generation of impurities will greatly affect the mechanical properties of the material, which is consistent with the experimental phenomena and relevant data obtained from measurement. This temperature is not conducive to the recovery of waste wind turbine blades. When the final pyrolysis temperature is 550.0 °C, the epoxy resin almost completely decomposes. Due to the high temperature resistance of glass fiber, there is almost no thermal decomposition. At this stage, the main part of the pyrolysis residue of blade materials are glass fiber. Due to the full decomposition of epoxy resin, the impurity content decreases, and the final mechanical properties are closer to glass fiber, which provides a basis for the recovery of glass fiber. Although the composition is more pure at this temperature, the mechanical properties of the material decrease greatly.

By calculating the typical mechanical properties of the blade samples pyrolysis residue at the three final pyrolysis temperatures compared to the loss rate of the original sample, the recycling value of the pyrolysis residue can be judged. The calculation results are shown in Table 2.

Table 2. Loss rate of mechanical properties of three pyrolysis residues.

Final pyrolysis temperature (°C)	Elastic modulus loss rate (%)
350.0	19.02
450.0	70.71
550.0	53.84

Comparing the mechanical properties of the original blade samples and the pyrolysis residues of blade materials at three temperatures, it can be found that the elastic modulus, tensile strength and elongation at break all decrease significantly, which shows that pyrolysis will reduce the mechanical properties of blade materials.

In conclusion, in order to ensure the mechanical properties of blade samples residues after pyrolysis process, when the pyrolysis temperature is set at 350.0 °C, the loss rate of elastic modulus of blade materials pyrolysis residues at this temperature is only 19.02 % of the original sample, and the pyrolysis residues with good elastic modulus and tensile strength can be recovered. At this time, a small amount of epoxy resin decomposes, it provides a basis for the resource recovery and utilization of glass fiber reinforced epoxy resin composites.

3.2 Micromorphology analysis of waste wind turbine blades after pyrolysis

Fig. 1 shows the SEM images of the microscopic topography of the blade samples at the final pyrolysis temperature of 350.0 °C, with magnifications of 1 K (a), 5 K (b) and 20 K (c).When the

final temperature of pyrolysis was 350.0 °C, the observation and comparison of the apparent images and microstructures before and after pyrolysis showed that the shape and structural stability of the glass fibers in the waste blade materials were kept well, and no melting shrinkage occurred which provides a basis for the recycling and utilization of glass fiber resources; The damage to the epoxy resin matrix is not serious, and a small amount of epoxy resin undergoes a pyrolysis reaction, and the resulting carbon residue combines with the binder to form a thin layer attached to the surface of the glass fiber, and the interface between the glass fiber and the epoxy resin is not completely destroyed.

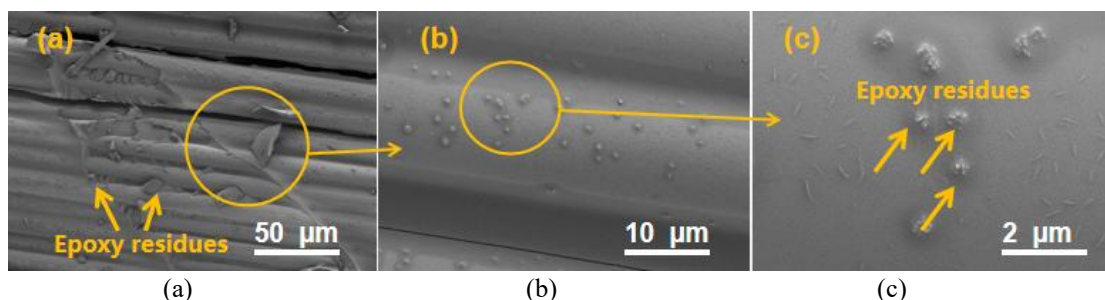


Fig. 1 SEM image of the pyrolysis residue of the blade samples at the final pyrolysis temperature of 350.0 °C (1 K (a), 5 K (b), 20 K (c)).

Fig. 2 shows the SEM images of the microscopic topography of the wind turbine blade materials at the final pyrolysis temperature of 450.0 °C, with magnifications of 1 K (a), 5 K (b) and 20 K (c). When the final pyrolysis temperature is 450.0 °C, the observation and comparison of the apparent images and micro morphology before and after pyrolysis can be obtained: the shape and structural stability of glass fibers in blade samples remain relatively good, some glass fibers melt and shrink, and there is a slight deviation in spatial sequence arrangement, which still has the value of resource utilization and recovery of glass fibers; A large number of epoxy resins undergo pyrolysis reaction, and the pyrolysis reaction enters the stage of rapid mass loss of the main body. More molten matrix and matrix blocks melt, fall off and bulge appear on the surface, reflecting the fluidity of the softened and melted epoxy resin matrix in the process of thermal degradation. There is an obvious debonding interface between glass fiber and epoxy resin matrix, and the ash after epoxy resin combustion is distributed on the surface of glass fiber as powder.

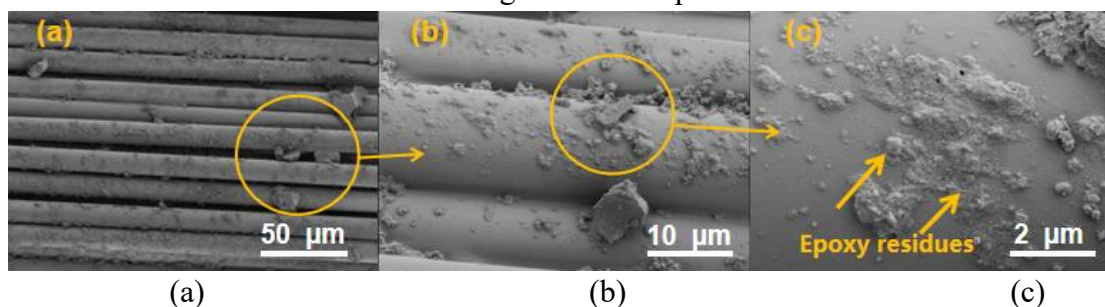


Fig. 2 SEM image of the pyrolysis residue of the blade samples at the final pyrolysis temperature of 450.0 °C (1 K (a), 5 K (b), 20 K (c)).

Fig. 3 shows the SEM images of the micro-morphology of the residue of the blade samples at the final pyrolysis temperature of 550.0 °C, with magnifications of 1 K (a), 5 K (b) and 20 K (c). The glass fiber maintains a good spatial structure, the quality of the pyrolysis solid residue hardly changes, the pyrolysis reaction stage enters the mass loss slowing stage, the attachments on the microscopic surface of the glass fiber are reduced, and the molten epoxy resin appears to be completely carbonized black, and the presence of a small amount of epoxy resin traces indicates the high degree of pyrolysis of the epoxy resin, resulting in a relatively smooth fiber surface and complete debonding of the interface between the glass fiber and the epoxy resin matrix. Therefore, it can be inferred that the surface epoxy resin has been basically completely decomposed and carbonized [13].

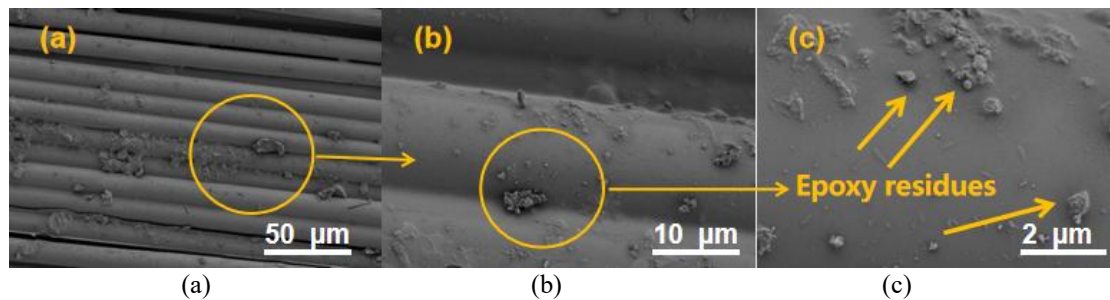


Fig. 3 SEM image of the pyrolysis residue of the blade samples at the final pyrolysis temperature of 550.0 °C (1 K (a), 5 K (b), 20 K (c)).

Since the epoxy resin matrix is mainly decomposed in the tested temperature range, and the glass fiber itself is not decomposed, the residual amount of epoxy resin represents the thermal degradation rate and the degree of pyrolysis. High temperature pyrolysis attacks the cured epoxy cross-linked network, causing it to begin to disintegrate. With the increase of the final pyrolysis temperature, the degradation of the epoxy resin matrix is more complete, and the thermal degradation accelerate the deterioration of the adhesion between the glass fiber and the epoxy resin matrix.

4. Summary

In this paper, mechanical properties and surface microscopic properties of waste wind turbine blade samples (glass fiber reinforced epoxy resin composites) were discussed. For the pyrolysis of blade materials in the nitrogen atmosphere, with the rise of final pyrolysis temperature, the elastic modulus and tensile strength of waste blade materials first decrease and then increase, but the increase range is far less than the decrease range. When the pyrolysis temperature is 350.0 °C, a small amount of epoxy resin is decomposed, and the loss rate of elastic modulus of pyrolysis residue of blade materials at this temperature is low. During the pyrolysis process, the change of the micro morphology of the blade materials are mainly in the epoxy resin part, with the increase of the final pyrolysis temperature, the interface stability between the epoxy resin and the glass fiber are destroyed. The glass fiber in the composite composition of the blade materials always maintain a stable structure and state, while the epoxy resin matrix is gradually decomposed into components with lower molecular mass, which can be recycled in some case.

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