EFFECTS OF HUMID AND HOT ENVIRONMENT ON FIBER COMPOSITES IN COOLING TOWERS

by

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Polyvinyl chloride materials used in cooling towers always lead to damage and low efficiency due to the hot and humid environment. This paper suggests a glass fiber reinforced material for a better performance. An optimal fractal distribution-of glass fibers in the composite matrix is experimentally obtained when the fractal dimensions are between 0.6 and 0.9.

Key words: *fiber composite, material properties, polypropylene, water collector, two-scale fractal dimension, fractal Hall-Petch theory, inverse Hall-Petch effect*

Introduction

At present, more than 1 billion people live in water-deficient areas and as many as 3.5 billion people will face serious water shortages by 2025. According to a recent report released by the world water institute, three approaches are most effective in addressing the water crisis: improving agricultural efficiency, investing in water infrastructure, and enhancing sustainable water recycling. As a large industrial water user, thermal power plants and chemical production have noteworthy significance in reducing the water vapor loss through improving efficiency of open cooling towers. The water collector is an important device in the industrial cooling tower in order to reduce part of water evaporation and wind blow loss, so as to achieve water saving efficiency. Generally, the water collector is installed on the upper part of the cooling tower packing layer to intercept the water in the cooling tower and its structure and functional design determine the water collection effect [1].

Since the water collector runs in a warm and humid cooling tower environment all year round, the temperature can reach as high as about 50 °C and the humidity is about 98%. This environment is suitable for the fast growth of many kinds of microorganisms, among which the slime-forming bacteria can directly cause metal corrosion. The surface of a heat exchange tube covered with slime affects the cooling effect of cooling water. In addition, the water collector should not only bear the force of gravity and air-flow, but also bear the load brought by sludge and clumps [2].

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Therefore, the material of the water collector must meet the following requirements: firstly, it has good thermal stability in a hot and humid environment at 50 °C; secondly, it must have sufficient rigidity when there is a certain wind vibration effect at high wind speed (up to 4-5 m/s in the mechanical tower); thirdly, it can maintain a long enough service life under the current economic conditions and it will not cause aging and deformation for more than 8 years; finally, it must have good low temperature resistance and it should not be broken or brittle under the conditions of low temperature of –40 °C and a certain snow load.

Up to now, most of the water collectors used by thermal power plants and chemical enterprises are corrugated plate collectors, whose materials mainly include polyvinyl chloride (PVC) and glass reinforced plastic materials. The PVC material water collector works in the hot and humid environment of the cooling tower for a long time, the heat resistance is insufficient, it is easy to deform, and the service life is short. It usually needs to be replaced in 1-2 years. At about 50 °C, hydrogen chloride gas will slowly produce, which is toxic. However, PVC material is widely used in cooling towers of power plants because of its low cost. The glass fiber reinforced plastic water collector products have high strength and long service life, but it has low production efficiency and high cost. The water-saving performance of the aforementioned two kinds of water collectors has been unable to meet the needs of the vast areas, especially the water shortage areas. In view of the shortcomings of the existing water collector, it is necessary to optimize the design of the material, forming process and service life of the water collector [3].

Glass fiber reinforced materials are mostly structural engineering materials, which are often used on structural parts of products. Chopped glass fibers are evenly dispersed in the composite material, which can improve the mechanical properties of the matrix [4]. The matrix keeps the fibers in a relatively stable position so that they can act synergistically, and can protect the fibers from damage from the external environment, and play a role of transmitting and bearing of various external forces. Therefore, determining the reasonable proportion of fibers is a key factor [5].

We aim to develop a new type of short fiber composite water collectors using glass fiber as the reinforcement and thermoplastic resin polypropylene as the matrix to produce high performance glass fiber/polypropylene composite water collector. By controlling the content of glass fiber and combining the injection molding process [6, 7], the material components meeting the performance requirements of the water collector are determined.

Experiments

Considering that the water collector operates in an open environment with humid water vapor and ultraviolet radiation all year round, it is planned to use fiber reinforced composite materials to meet the material requirements for the new type of water collecting device. Fiber reinforced composites are characterized by light weight, high specific strength, corrosion resistance, good electrical insulation, slow heat transfer and good thermal insulation. At the same time, the dielectric properties of the reinforcing fiber do not change significantly with the temperature and frequency, and the failure of the composite material is the accumulation of internal microscopic failure, lasting a long time.

Polypropylene material is a thermoplastic resin. It has good heat resistance, a melting point of up to 167 °C and a density of 0.90 g/cm^3. It is the lightest general-purpose plastic and has excellent corrosion resistance. Common acids and alkali organic solvents have little effect on it. The disadvantages of poor resistance to low temperature impact and easy aging can be overcome by modifying and adding antioxidants. Chopped fiber composite materials can be cut to a certain length-to-diameter ratio and composited with the matrix. Considering the shape, actual processability, product quantity and efficiency of the water collecting device, this article uses chopped glass fiber reinforced matrix for injection molding compound.

The proportion of fibers in the composite material will affect the mechanical properties. The volume percentage of the fibers is too low to achieve the reinforcement effect, and too high will cause technical difficulties. Therefore, performance testing of glass fiber reinforced polypropylene matrix materials with different volume contents is required to determine the most suitable glass fiber content. The samples were made by injection molding with 10%, 15%, 20%, 30%, and 35% of the fiber content, and were tested for tensile and flexural properties. The variation trend of tensile strength under different fiber contents is shown in fig. 1.

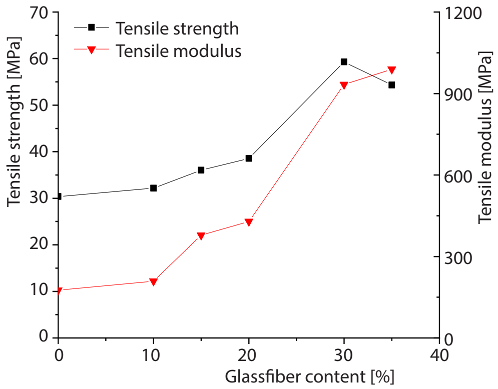

Figure 1. Effect of glass fiber content on tensile properties of composites

When the fiber content is less than 20%, the tensile strength of glass fiber reinforced polypropylene composites increases gradually. In particular, when the fiber content is 30%, the tensile strength of the material increased from 30.36-59.28MPa, nearly doubling its strength. But when the fiber content is higher than this threshold, the tensile strength decreases. This shows that the addition of short glass fiber can effectively improve the tensile properties of the composite material, especially when the fiber content is between 20% and 30%, the two-scale fractal dimensions are, respectively [8-10]:

$$D = 3\times 20\% = 0.6 \tag{1}$$

$$D = 3\times 30\% = 0.9 \tag{2}$$

The flexural properties of different samples were tested, and the influence of fiber content on the bending properties was shown in fig. 2.

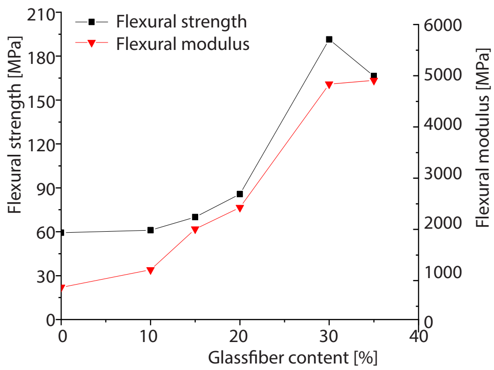

Figure 2. Effect of fiber content on the flexural properties of the composites

According to the fractal Hall-Petch theory, the strength of the fiber-enforced material can be expressed [11, 12]:

$$\sigma=\sigma_0+\frac{k}{r^{2-\alpha}} \tag{3}$$

where σ_0 is the strength without glass fibers, r – the fiber length, k – the material constant, and α – the sectional two-scale fractal dimensions:

$$\alpha=\frac{2}{3}D \tag{4}$$

Equation (3) can be re-written:

$$\sigma=\sigma_0+\frac{k}{r^{2(1-D/3)}} \tag{5}$$

In our experiment, the inverse Hall-Petch effect happens when fiber content reaches 35%, $D = 3 \times 35\% = 1.05$.

As can be seen from fig. 2, with the increase of fiber content, the bending modulus of the composite material is also enhanced. The fiber content is within the range of 20-30%, and the increase is the most obvious. When the fiber content is 30%, the flexural modulus reaches the maximum. However, when the fiber content reaches 35%, it decreases.

By comparison, it can be concluded that the performance of pure polypropylene materials without glass fibers is the worst. The addition of 30% glass fibers improves the overall performance of the material, which maximizes the tensile strength, bending strength, and flexural modulus. Considering the effect of the amount of chopped fiber on the mechanical properties and flow properties of the plastic part, to ensure that the melt is fully filled and to obtain as good mechanical properties as possible, it is finally determined that the glass fiber volume content is 30% to prepare the composite material.

Results and discussion

The simulation experiment was carried out under the same working conditions to compare the traditional PVC material with the composite material prepared in this paper. Here the same working condition mainly refers to: under the condition of basically the same surrounding environment (indoor temperature, outdoor temperature, air humidity and atmospheric pressure), the water density, fan speed and hot water temperature in the cooling tower are the same.

Tensile properties

Five samples of PVC corrugated board material and five fiberglass reinforced polypropylene composite materials were selected for effective test, and a static tensile load was applied along the axial direction of the sample using an electro-hydraulic servo universal testing machine (range 50 tones). When the specimen breaks, the tensile stress, tensile strength, and tensile elastic modulus are calculated (tab.1) and the stress-strain curve is plotted, fig. 3.

Table 1. Comparative experimental results of different material properties

	Properties	Traditional PVC material	Homemade fiber composites
F_m [N]	Maximum force	345.78	2963.95
Agt. [%]	Maximum total elongation	14.03	5.92
E [MPa]	Elastic modulus	107.57	933.36
R_m [MPa]	Tensile strength	63.16	472.6
W_t [Nm]	Total energy	4.756	5.27

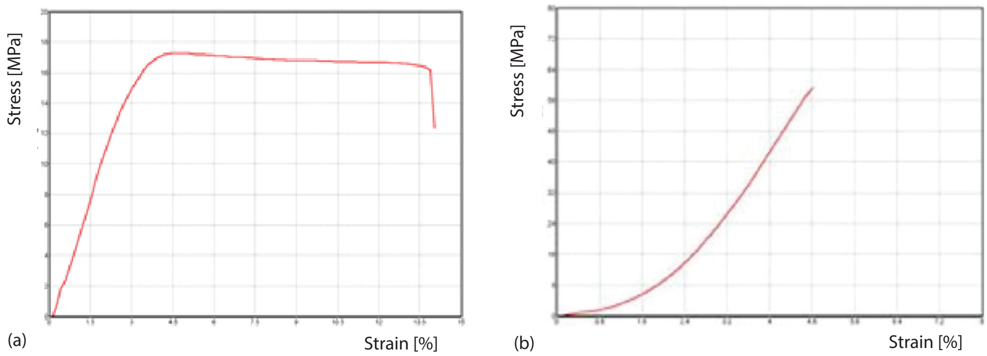

Figure 3. Comparison of the stress-strain curves of the tensile properties of the two materials; (a) stress-strain curve of PVC material, (b) stress-strain curve of fiber composites

It can be seen from tab.1 that the tensile properties of the glass fiber reinforced polypropylene composite material are much higher than those of the traditional corrugated PVC material, which meets the installation strength. It can be seen from fig. 3 that the PVC sample is approximately a straight line in the 3% strain range. After the strain reaches the tensile strength limit, the material softens, and each increment of newly added strain requires relatively small stress. The fiber-reinforced polypropylene composite material has a phenomenon of pre-shrinkage, and the chopped fiber composite material has a relatively large plasticity and a large elastic deformation.

Fl exural properties

A three-point bending test was performed on a sample of a corrugated board material of PVC and a sample of chopped fiber-reinforced polypropylene composite material using an unconstrained support using a bending tester. Load the specimen at a constant rate until the specimen breaks or reaches a predetermined deflection value. During the experiment, the load applied to the sample and the deflection of the sample were measured to obtain the bending strength, bending elastic modulus of the material, tab. 2, and the curve relationship between bending stress and strain, fig. 4.

Table 2. Comparative experimental results of properties of different composite materials

Traditional PVC material			Glass fiber reinforced polypropylene composite		
E_b	Flexural modulus	833.41 MPa	E_b	Flexural modulus	4704.97 MPa
f	Deflection	6.88 mm	f	Deflection	3.64 mm
σ_{bb}	Flexural strength	59.94 MPa	σ_{bb}	Flexural strength	191 MPa
f_{bb}	Deflection at break	15.9 mm	f_{bb}	Deflection at break	4.07 mm
F_{bb}	Bending force	208.12 N	F_{bb}	Bending force	664.62 N

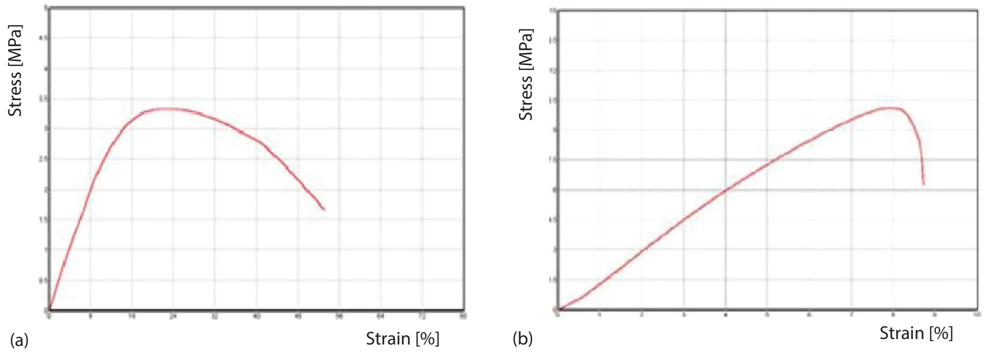

Figure 4. Comparison of the stress-strain curves of the flexural properties of the two materials; (a) stress-strain curve of PVC material, (b) stress-strain curve of fiber composites

According to the data in tab. 2, it can be seen that the flexural elastic modulus of the self-made glass fiber reinforced polypropylene composite material reaches 4.7 GPa and the bending strength is 191 MPa, which is much higher than that of the traditional corrugated PVC material, which fully meets the cooling tower. Requirements for the mechanical performance of the water separator. It can be seen from the fig. 4 that the fiber reinforced polypropylene composite material has higher modulus and tensile strength than the PVC corrugated board.

Damp heat aging performance

Select PVC sheet samples and glass fiber-reinforced polypropylene composite materials for each group of five, and use the DHS-225 constant temperature and humidity experiment box to allow the samples to be under constant or alternating humidity and heat conditions. Changes in appearance and mechanical properties were measured. Select constant humid heat test conditions: temperature of 50 °C, relative humidity of 98%. Take 24 hours as an experimental cycle. As the wet heat aging progresses, the tensile properties of glass fiber reinforced composites are shown in fig. 5.

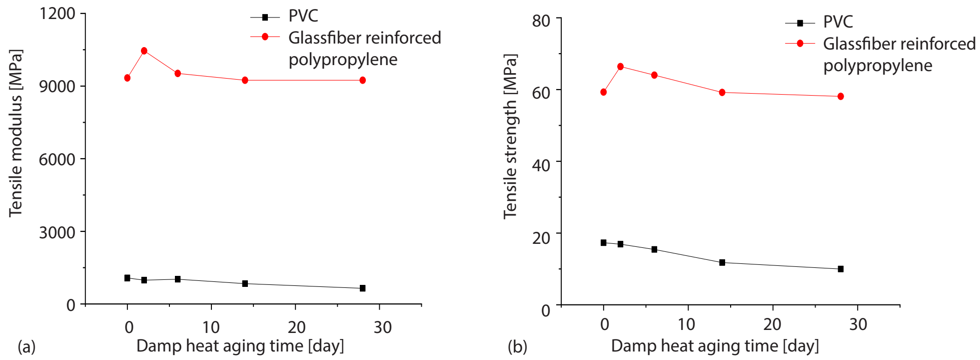

Figure 5. Effect of damp heat aging on tensile modulus and tensile strength; (a) tensile modulus, (b) tensile strength

It can be seen from fig. 5 that after two days of wet heat treatment, the performance of the fiber-reinforced composite material increased slightly. This is because the material is in a certain temperature and humidity environment. The effect of temperature and humidity improves the internal thermal stress of the material, so the elongation performance is improved. The tensile strength of PVC is greatly reduced during the 28 days wet heat aging process, mainly because the heat resistance range of PVC is usually not higher than 55 °C, and the ambient temperature in the cooling tower is about 50 °C. In comparison, the anti-aging performance of fiber reinforced polypropylene composites is higher than that of PVC water collection devices, and temperature and humidity have little effect on its tensile properties.

Figure 6 shows the changes in flexural strength and flexural modulus of glass fiber reinforced composite materials and PVC materials under aging conditions in humid heat.

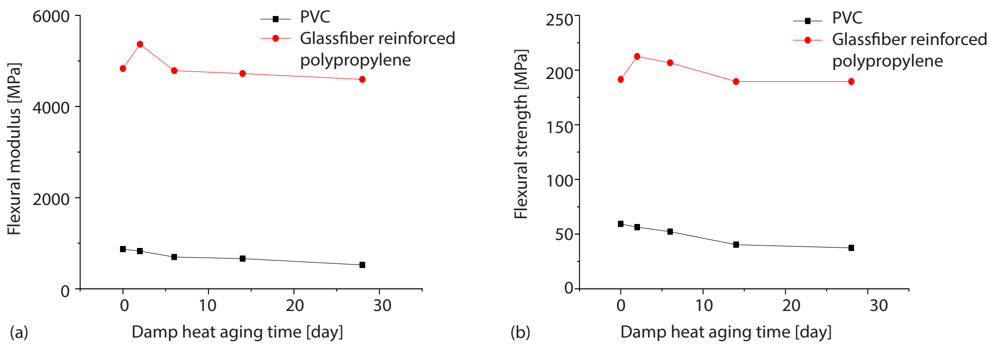

Figure 6. Effect of damp heat aging on flexural modulus and flexural strength; (a) flexural modulus, (b) flexural strength

It can be seen from fig. 6 that the bending strength and bending modulus of the material will decrease to varying degrees with the increase of the aging time. After 28 days, the flexural strength of PVC decreased from 59.3-37.36, a decrease of 37%, and the fiber-reinforced polypropylene decreased from 191.41-189.5, a decrease of 1%. The flexural modulus of PVC retention was 60%, and the retention of glass fiber reinforced polypropylene was 95%. It can be seen that the bending mechanical properties of PVC materials are significantly reduced, and the mechanical property retention rate of fiber-reinforced composite materials is high. The water collector has higher requirements for the material's resistance to humidity and heat aging because it operates in a certain temperature and humidity environment all year round. Therefore, the glass fiber reinforced polypropylene studied in this paper has better resistance to moisture and heat aging than PVC.

Conclusion

In this paper, the materials of the new swirling water collecting device are designed to overcome the shortcomings of traditional materials such as poor heat resistance, easy damage, and short life. The performance of chopped long glass fiber reinforced polypropylene with a volume content of 30% is more in line with the material performance requirements of the water collecting device. The mechanical properties of fiber composite materials are tested and analyzed. The tensile test, bending test, and anti-aging properties are mainly studied. Compared with traditional PVC corrugated board materials, the results show that the performance of fiber composite materials is much higher. For the performance of PVC material, it meets the requirements of the collector material performance in the hot and humid environment of the cooling tower.

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