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Study on the Properties of GF/PVC Composite Prepreg Prepared Based on Electrostatic Powder Spraying Technology

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Abstract. In this paper, the electrostatic powder spraying technology is introduced into the dry powder impregnation process, and GF/PVC composite prepreg with a thickness of only 0.16 mm and a tensile strength of more than 200 MPa is successfully prepared. This study successfully solve the problems of high melt viscosity, difficult plasticization and difficult processing by traditional impregnation of PVC resin, and improve the performance of PVC composites. The step-by-step optimization of the production process not only provides a new method for the efficient preparation of PVC composites, but also provides strong support for the technological progress and application expansion in the field of composites.

Keywords: GF/PVC; electrostatic powder coating; fiber content; porosity; mechanical properties

1. Introduction

Polyvinyl chloride (PVC), as one of the earliest plastic varieties to be industrially produced in the world, has excellent flame retardant, insulating and corrosion-resistant properties, and is widely used in the industries of pipes, profiles and cable insulation.[1-6] However, the PVC material has the disadvantages of low notched impact strength, poor toughness, poor thermal stability, etc., which greatly limits the expansion of its application areas, and the preparation of composites by fiber reinforcement of PVC resin is an important way to greatly improve its comprehensive performance.[7-8]

Glass fiber (GF) is a reinforcing fiber made from inorganic mineral materials drawn at high temperatures and is widely used in composites because of its high strength, high modulus and chemical stability.[9-11] Compounding GF with PVC can significantly enhance the overall performance of the material while retaining the reinforcing properties of GF and the excellent chemical stability of PVC.[12]

In recent years, with the rapid development of new impregnation technology on FRTPC at home and abroad, which provides unprecedented possibilities to realize the preparation of high-performance fiber-reinforced PVC composites. However, the current research on the preparation technology of fiber-reinforced PVC composites is still relatively scarce, especially the exploration of the compatibility and performance optimization of the impregnation process with PVC resin is still in its infancy. Therefore, the development of innovative impregnation processes and molding equipment suitable for the characteristics of PVC resin has become the key to enhancing the performance of PVC composites.

Therefore, in this paper, electrostatic powder spraying technology is introduced into the dry powder impregnation process, from which GF/PVC composite prepreg is prepared. And in the electrostatic powder spraying process, the static voltage size and spraying distance, as the important process parameters to control the spraying quality, play a crucial role in the material properties. Therefore, in this paper, the two key parameters, static voltage size and spraying distance, are systematically regulated through experiments to investigate their effects on the properties of GF/PVC composite prepregs, thus providing an important theoretical basis for the efficient preparation of GF/PVC composites, and further providing a production guide for the application of thermoplastic composites in practical engineering.

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2. Experimental

2.1 Materials

PVC resin powder (SG-8), GF (ECT 4305PM-1200), calcium-zinc heat stabilizer (HJ-615), and plasticizer (S60-A), of which the PVC resin powder was purchased from Shanxi Beiyuan Chemical Group Co., Ltd., Shanxi, China, the GF was purchased from Chongqing International Composites Co., Ltd., Chongqing, China, the calcium-zinc heat stabilizer was provided by Anhui Huajie Hengye New Material Technology Co., Ltd., Anhui, China, and the plasticizer was provided by Suzhou Ningsheng Chemical Co., Ltd., Jiangsu, China.

2.2 Preparation

Firstly, the glass fiber placed on the yarn frame was guided to the mechanical roller spreading device to realize the unfolding of the fiber bundle under the traction effect of the traction device. Then, the PVC formulation was coated on the fiber by the electrostatic powder coating device, and after being melted and plasticized by the heating device, it gradually achieved the complete coating of the entire fiber surface. Finally, the GF/PVC composite prepreg was further compacted under the action of the roller pressing device and wound up by the traction device, thus completing the whole preparation process of GF/PVC composite prepreg. The prepared GF/PVC composite prepreg was shown in Figure 1.

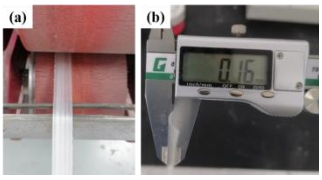

Figure 1. GF/PVC composite prepreg

2.3 Performance Characterization

The fiber mass fraction in the GF/PVC composites prepreg was determined by the burnout method. The principle of measurement was shown in equation (1):

$$w_f = \frac{m_3 - m_1}{m_2 - m_1} \times 100\% \tag{1}$$

Where: w_f-GF/PVC composite prepreg fiber mass fraction, wt%; m_1-empty crucible mass, g; m_2-total mass of the crucible and the sample to be tested, g; m_3-total mass of the crucible and the fibers after the completion of the scorching, g.

The actual density ρ_s of the GF/PVC composite prepreg was determined using a multifunctional electronic densitometer, from which the porosity k of the GF/PVC composite prepreg could be further calculated:

$$k = \frac{\rho_c - \rho_s}{\rho_c} \tag{2}$$

Where: k-GF/PVC composite prepreg porosity; ρ_c-GF/PVC composite prepreg theoretical density, g/cm^3; ρ_s-GF/PVC composite prepreg actual density, g/cm^3.

The tensile strength of GF/PVC composite prepreg was tested using a universal testing machine according to the determination method described in the standard GB/T 32788.4-2016.

3. Results and Discussion

3.1 Fiber Content and Porosity of GF/PVC Composite Prepreg

For fiber reinforced composites, in general, its mechanical properties will be enhanced with the increase of fiber content, but when the fiber content is too high, it will lead to a sharp increase in the internal porosity of the material, making the material mechanical properties greatly reduced.

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The variation of static voltage and spraying distance on the fiber content and porosity of the prepared GF/PVC composite prepreg is shown in Figure 2. When the variation of static voltage size in the range of 50~90 kV does not have a significant effect on the fiber content of the material, and there is only a 1.2% difference between the maximum values of the fiber content of the material, as shown in Figure 2a. This is due to the fact that there is a maximum charge value for the powder under the corona charging mechanism, and once the charge on the surface of the powder reaches this limit value, the net electrostatic force on the powder does not change, and the resulting material is able to achieve a relatively constant fiber content. However, a higher static voltage can make the resin powder have a higher charging efficiency, so that it can be deposited more uniformly and efficiently on the surface of the fiber under the action of electric field force to form a continuous and dense resin layer, thus strengthening the interfacial bonding with the fiber, so that the material porosity has a minimum value of 4.9% when the static voltage magnitude is 90 kV, as shown in Figure 2b.

Comprehensive Figure 2c and Figure 2d show that with the increase of spraying distance, the fiber content and porosity of the material show a decreasing and then increasing trend. When the spraying distance is 60 mm, the fiber content and porosity of the material are 39.6% and 4.7%, respectively. A simulation study find that in the electrostatic powder spraying process, with the change of spraying distance, the flow field and electric field distribution in the spraying area will be affected to different degrees, and this multifactorial joint effect makes the spraying distance exist an almost optimal value.

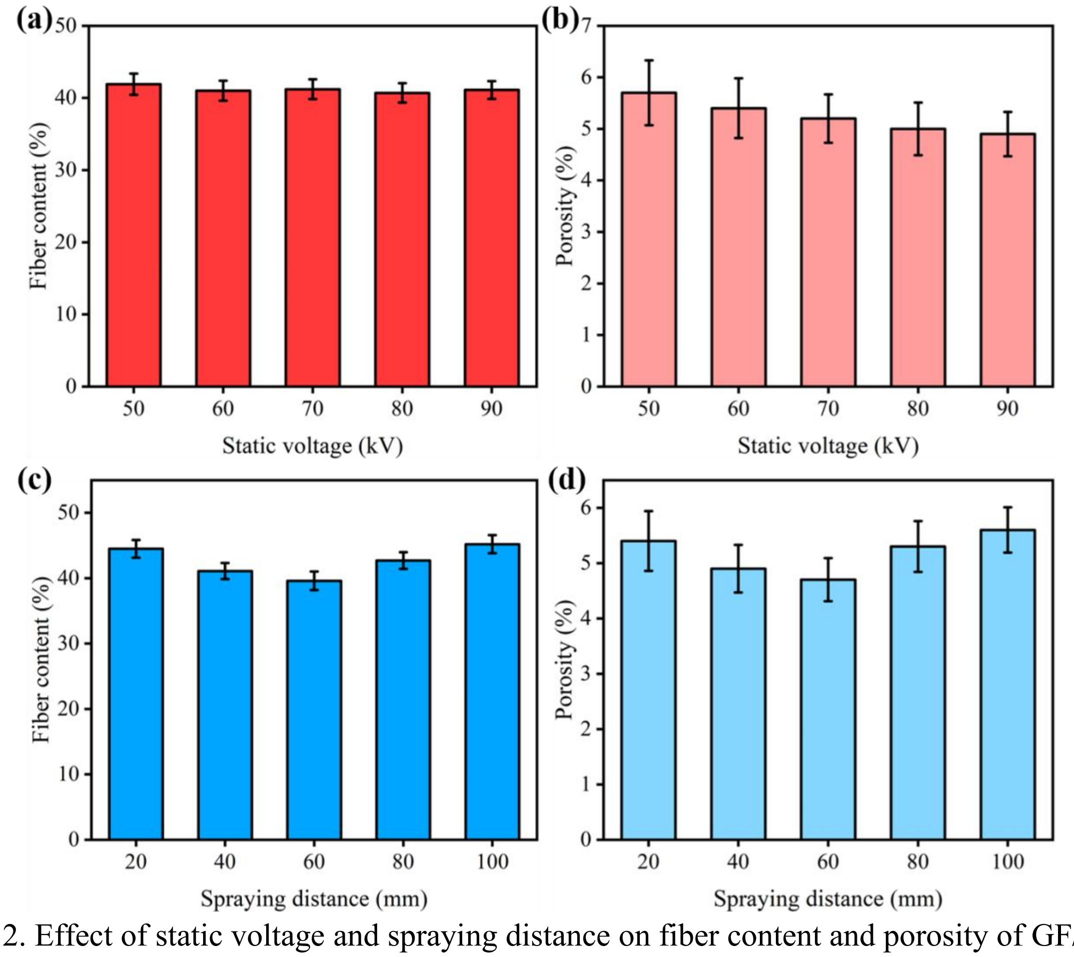

Figure 2. Effect of static voltage and spraying distance on fiber content and porosity of GF/PVC composite prepreg (a-b) Effect of static voltage magnitude on fiber content and porosity of GF/PVC composite prepreg (c-d) Effect of spraying distance on fiber content and porosity of GF/PVC composite prepreg

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3.2 Tensile Strength of GF/PVC Composite Prepreg

To further validate the above results, this subsection explores the tensile strength magnitude of the GF/PVC composite prepreg prepared based on the above static voltage and spraying distance with a view to determining an optimal range of static voltage magnitude and spraying distance.

The variation of static voltage and spraying distance on the tensile strength of the prepared GF/PVC composite prepreg is shown in the pattern in Figure 3. From Figure 3a, it can be seen that with the increasing static voltage, the tensile strength of the material increases from the initial 189.3 MPa to 201.6 MPa with a growth rate of 6.5%, which is mainly due to the weak decrease in the porosity of the material. With the spraying distance increasing from 20 mm to 100 mm, the tensile strength of the material shows the trend of increasing and then decreasing, and reaches the maximum value of 201.6MPa when the spraying distance is 40 mm. when the spraying distance is more than 40mm, its tensile strength decreases from 201.6MPa to the final 172.1MPa, and the degree of decrease reaches 14.6%, as shown in Figure 3b.

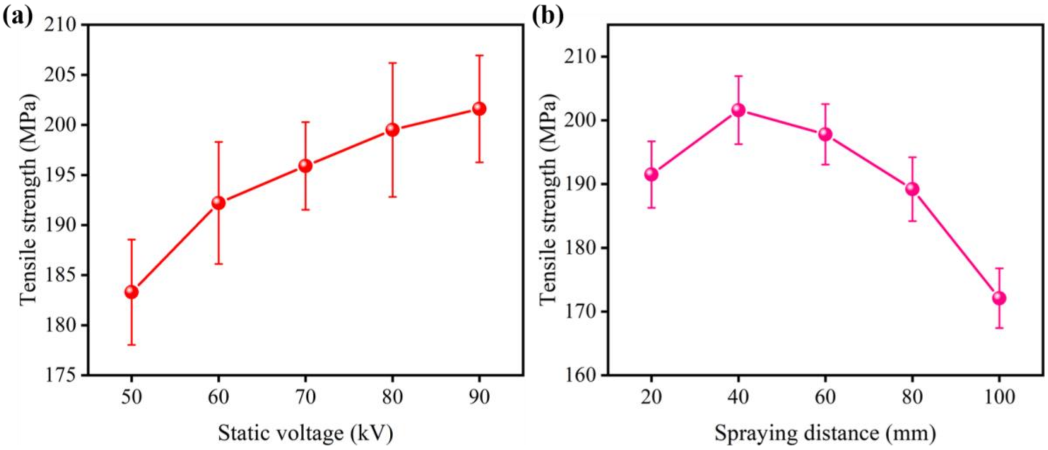

Figure 3. Effect of static voltage and spraying distance on the tensile strength of GF/PVC composite prepreg (a) Effect of static voltage magnitude on the tensile strength of GF/PVC composite prepreg (b) Effect of spraying distance on the tensile strength of GF/PVC composite prepreg

Therefore, through the above study, it can be assumed that during the electrostatic powder coating process, when the static voltage magnitude is at 80~90 kV and the spraying distance is located at 40~60 mm, the prepared material has a higher mechanical properties and fiber content as well as a lower porosity.

4. Summary

(1) Due to the corona charging mechanism effect, the variation of static voltage magnitude in the range of 50~90 kV does not significantly affect the mechanical properties of the prepared GF/PVC composite prepreg.

(2) When the spraying distance varies from 20 to 100 mm, the fiber content and porosity of the prepared GF/PVC composite prepreg show a trend of decreasing and then increasing, and are at a very small value when the spraying distance is 60 mm.

(3) When the static voltage magnitude is 90 kV and the spraying distance is 40mm, the tensile strength of the prepared GF/PVC composite prepreg can reach 201.6MPa.

References

[1] Safarpour M, Safikhani A, Vatanpour V. Polyvinyl chloride-based membranes: A review on fabrication techniques, applications and future perspectives[J]. Separation and Purification Technology, 2021, 279: 119678.

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P78
[2] Wang Y, Kang N, Lin J, et al. On the pyrolysis characteristic parameters of four flame-retardant classes of PVC sheathless cable insulation materials[J]. Journal of Analytical and Applied Pyrolysis, 2023, 170: 105901.

[3] Elgharbawy A. Poly vinyl chloride additives and applications-a review[J]. Journal of Risk Analysis and Crisis Response, 2022, 12(3).

[4] Pan Y T, Yuan Y, Wang D Y, et al. An overview of the flame retardants for poly (vinyl chloride): recent states and perspective[J]. Chinese Journal of Chemistry, 2020, 38(12): 1870-1896.

[5] Mijangos C, Calafel I, Santamaría A. Poly (vinyl chloride), a historical polymer still evolving[J]. Polymer, 2023, 266: 125610.

[6] Edraki M, Sheydaei M, Alinia-Ahandani E, et al. Polyvinyl chloride: chemical modification and investigation of structural and thermal properties[J]. Journal of Sulfur Chemistry, 2021, 42(4): 397-409.

[7] Bishay I K, Abd-El-Messieh S L, Mansour S H. Electrical, mechanical and thermal properties of polyvinyl chloride composites filled with aluminum powder[J]. Materials & Design, 2011, 32(1): 62-68.

[8] Li Y, Ding C, Zhang N, et al. High-value utilisation of ceramic waste powder in PVC-based composite and basalt fibre reinforcement effect on its performance[J]. Ceramics International, 2022, 48(13): 18083-18093.

[9] Baumard T, Menary G, De Almeida O, et al. Experimental characterization and modeling of the temperature and rate-dependent shear behaviour of powder-impregnated glass fiber/PA66 woven semipregs[J]. Composites Science and Technology, 2019, 180: 23-32.

[10] Li Y, Li Y, Huan D, et al. Study on polyetheretherketone prepreg manufactured by aqueous system of powder impregnation[J]. Polymer Composites, 2022, 43(5): 2980-2991.

[11] Yang Y, Lai Y, Zhao S, et al. Optically transparent and high-strength glass-fabric reinforced composite[J]. Composites Science and Technology, 2024, 245: 110338.

[12] Wang S, Liu Y, Chen K, et al. Thermal and mechanical properties of the continuous glass fibers reinforced PVC composites prepared by the wet powder impregnation technology[J]. Journal of Polymer Research, 2020, 27: 1-12.