Research on Preparation Technology for Continuous Carbon Fiber Reinforced Printing Filaments

Xiangjun Bi¹,* , Hongsheng Tan², Zonghui Li³, Yuqin Li¹ and Tengfei Liu⁴

¹ Aerospace Research Institute of Special Material and Processing Technology, Beijing, China
² Shandong University of Technology, Zibo, China
³ Hua Dian Electric Power Research Institute Co., LTD., Beijing, China
⁴ Xi’an Jiaotong University, Xi’an, China

*Corresponding author e-mail: bxiangji163.com

Abstract. Continuous carbon fiber reinforced thermoplastic composites with high mechanical strength can make up for the low-bearing faults of pure resin material and particle reinforced material. At the same time, the physical properties of fiber conduction can meet the structure damage detection and conductive functional requirements. It is seen as one of the advanced technology in thermoplastic 3D printing field. At present, the material has been gradually used in robot manufacturing, aerospace components manufacturing and so on. This paper introduces the preparation process of continuous fiber reinforced printing filaments and the characterization of mechanical properties, morphology and printing results. It points out that the printing filaments can meet the basic requirements of continuous fiber reinforced printing, which with high fiber orientation is affected by prepreg tension function. In addition, the small diameter filaments have obvious advantages in transportation, printing fabrications and printing effects. It is suggested that continuous fiber reinforced printing is suitable for choosing filaments with the diameter of 0.4mm or less.

Keywords: Additive manufacturing, 3D printing, FFF, filament fabrication

1. Introduction

With the development trend of low cost and intelligentization of composite materials and some requirements (short cycle development, rapid prototyping, simple preparation of complex components and environment-friendly manufacturing), a new composite material manufacturing concept, additive manufacturing (i.e. 3D printing), is proposed. It is a new manufacturing method by adding materials and manufacturing layer by layer, and a quick manufacturing way of physical objects consistent with the three-dimensional model. At the same time, it is a best way to solve the contradiction between low cost, quick molding and the requirements of products high performance, which has an important impact on product design, manufacturing and maintenance mode. And it is known as the core technology of the "third industrial revolution". [1] 3D printing and specifically fused filament fabrication (FFF) have brought about a new dimension to the fabrication of PCs. [2, 3] Now the United States has issued and supported several programs which integrate 3D printing into the country’s manufacturing strategy, such
as NGMTI (in 2006) [4], NNMI (in 2012), A 21st Century Science, Technology and Innovation Strategy for America's National Security, Emerging Science and Technology Trends: 2016-2045--A Synthesis of Leading Forecasts (APRIL. 2016) [5]. The research institutes and enterprises involved include Binstate University, University of Alabama, Massachusetts institute of technology, Oak Ridge National Laboratory, Lockheed Martin, Boeing, and so on [6]. In China, 3D printing technology has also been promoted to a very important position, and issue the Plans: the Development and Promotion of the National Additive Manufacturing Industry 2015-2016, the Plan for the Development and Action of the National Additive Manufacturing Industry 2017-2020 [7, 8, 9].

Filaments for 3D printing, especially for thermoplastic resin matrix composites, have become a bottleneck in the development of printing technology, which limits the stability and safety of 3D printing products. At present, filaments reinforced with small particles or chopped fiber is given priority, such as chopped glass fiber reinforced PP, ABS or PLA; they have low mechanical strength, tensile strength under 100 MPa), low weather resistance, low heat resistance and poor ultraviolet resistance performance, far less than the traditional fiber reinforced composite material. So these did not meet the requirements of aerospace structural use.[10] In this paper, the preparation of continuous fiber-reinforced nylon filaments was taken as the research object, and introduced the morphology, usage and printing status of two materials with different diameters were compared.

2. Experimental

2.1. Material preparation

Nylon, PA6, TP-4208, ZIG SHENG INDUSTRIAL CO., LTD. Carbon fiber, T700-12K, Toray. Carbon fiber, T700-1K, Jiangsu Hengshen Co. LTD. Filament Forming Equipment, self-made equipment; Continuous Fiber Printing Equipment, COMBOT-200, Shanxi Fibertech Co. LTD.

2.2. Technological Process

In order to ensure the continuity of fiber, the equipment of continuous fiber reinforced thermoplastic filaments is crossing form in prepreg process, which is different from linear flow design of discontinuous fiber wire [11], and has different prepreg form, mixed state, extrusion state and sizing technology. The following is a brief description of the molding process:

- Material pretreatment:
  - Dry fiber: PA6 was placed in a 90°C air-blast drying box and dried for 8h.
  - Dry plastic: The fiber was placed in a 90°C air-blast drying box and dried for 1h.

- Preimpregnated fibre, Screw extrusion: In this process, three sets of prepreg rolls were used to infiltrate the fiber into the nylon melt under the action of pressure.

- Wire sizing: Use special sizing equipment to control the final filament diameter.

- Air cooling: After passing through the high-temperature sizing equipment, the wire was cooled at room temperature and 2m away from the wire.

- Windig for use: Use a specified diameter plastic reel.

In this paper, two kinds of filaments with diameters of 1.75mm and 0.4mm were prepared. The fiber materials selected were one bundle of 12k carbon fiber and one bundle of 1k carbon fiber respectively.

2.3. Testing and Characterization

2.3.1. The tensile test. It is difficult to determine the bending performance of a filament with a diameter of 0.4mm. Here, a wire with a diameter of 1.75mm was used as the test object. The testing was conducted on the basis of ASTM D3039/D3039M Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials and ISO 3597-2:2003 Textile-glass-reinforced plastics-Determination of mechanical properties on rods made of roving-reinforced resin-Part 2: Determination of flexural strength. These tests were carried out using the universal testing machine (INSTRON Co., Instron 5969), as shown in figure 1.
2.3.2. Surface topography observation. The section morphologies of monofilament were measured and analyzed with the micro optical microscope (ANMO electronics corporation, AN413T).

3. discussion

3.1. Mechanical test
The measured data were respectively 820MPa (tensile strength) and 42GPa (tensile modulus). The strength data is close to the body of carbon fiber, which indicates that the fiber is consolidated and formed under the action of traction, and maintains a good fiber collimation.

3.2. Surface morphology analysis

Through the analysis of the fiber section morphology, it is found that there is no core-shell structure [12] in the fiber prepared by traction, but the resin and fiber are coated with each other and prepreg, forming a relatively uniform term. This may be because the fiber content is too high, which causes the fiber to occupy the volume of the resin. However, the mutual coating state between the fiber and the resin also indicates that the roll prepreg preparation process achieves the effect of complete prepreg of the fiber.
3.3. Effect of fiber diameter on winding state

Fig. 3 Wire with different diameters

a) A diameter of 1.75mm

b) A diameter of 0.4mm
According to figure 3, the winding diameter of the wire with a diameter of 1.75mm is very large. When the diameter exceeds 300mm, part of the filament is still broken, which has affected the use of printing. The winding diameter of 0.4mm wire is no more than 200mm, which can guarantee the original smooth and continuous state without any sign of breaking. This indicates that small diameter wires are more suitable for transportation and ensure the effective length of fibers.

3.4. Effect of fiber diameter on printing

![Figure 4. Comparison of printing effects of wires with different diameters](image)

a) Square sample with side length of 20mm (diameter of 1.75mm)

b) Print splines with length of 120mm (diameter of 0.4mm)

By comparing the printing effects of the two wires as shown in figure 4, it is found that compared with the filaments with 1.75mm, the sample with 0.4mm filaments has a small rotation return phenomenon and the space between adjacent fibers, and it can be guaranteed to turn back and print at a small Angle, which is more conducive to precision control and the printing of high-precision parts.

4. conclusion

Through the mechanical measurement, it can be predicted that the force action of the traction equipment can guarantee the consistency of the fiber direction, and the obtained wire with high orientation can meet the requirement of high strength of wire. At the same time, the fiber and resin in the fiber bundle were coated with each other, which indicated that the fiber was fully preimpregnated. The above shows that the preparation process is suitable for the preparation of continuous fiber reinforced nylon wire. By comparing the indexes of two kinds of filament with diameters (1.75mm and 0.4mm), it is shown that the small diameter wire is easy to be stored and used, and the printing defects (such as filaments and surface smoothness) are well guaranteed.

References

[1] Fabrizio Regina, Fulvio Lavecchia, Luigi Maria Galantucci. Preliminary study for a full colour low cost open source 3D printer, based on the combination of fused depositionmodelling (FDM) or fused filament fabrication (FFF) and inkjet printing. International Journal on
Interactive Design and Manufacturing (IJIDeM), 2018, 12:979–993.

[2] Yehia Ibrahim, Garrett W. Melenka, Roger Kempers. Additive manufacturing of Continuous Wire Polymer Composites. Manufacturing Letters, 2018, 16: 49–51.

[3] LUAN Cong-cong, YAO Xin-hua, LIU Cheng-zhe, FU Jian-zhong. Carbon fiber-thermoplastic composite 3D printing technology and its self-monitoring. Journal of Zhejiang University (Engineering Science), 2017, 09: 1808-1814.

[4] WANG Jianhua, LI Rupeng. Latest Development of Aircraft Digital Design and Manufacturing Technology. Aeronautical Manufacturing Technology, 2016, 05: 78-82.

[5] ZHU Hongkang, JIA Yudong. Research on Policies of American Manufacturing Innovation. Materials China, 2017, 05: 395-400.

[6] ZHANG Xuejun, TANG Siyi, ZHAO Hengyue, GUO Shaoqing, LI Neng, SUN Bingbing, CHEN Bingqing. Research Status and key technologies of 3D Printing. Journal of Materials Engineering, 2016, 44(2): 122-128.

[7] http://www.most.gov.cn/tztg/201304/t20130416_100885.htm.

[8] Xue Fengtong, Liu Haibin. The overview of friction stir additive manufacturing. Modern Manufacturing Engineering, 2019, 04: 33-40.

[9] AN Guojin. Application and prospect of metal additive manufacturing technology in aerospace. Modern Machinery, 2019, 03: 39-43.

[10] MING Yueke, DUAN Yugang, WANG Ben, XIAO Hong, ZHANG Xiaohui. 3D Printing for High Performance Fiber Reinforced Polymer Composites, Aeronautical Manufacturing Technology, 2019: 34-38

[11] Wu Hai-hua, Wang Jian, Cai Yu, Peng Jian-hui, Zhong Ji-hong, Wei Zheng-ying. Preparations and properties of graphene/PLA composite wire for 3D printing. CARBON TECHNIQUES, 2018, 6(37): 61-65.

[12] XIAO Jian-hua. Extrusion of Carbon Fiber Reinforced Thermoplastic Plastics for 3D-Printing. CHINA PLASTICS INDUSTRY, 2016, 44(6): 46-48.