Design and Implementation of 3D Printing System for Continuous CFRP Composites

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Abstract. The rapid and low-cost manufacturing of continuous Carbon Fiber Reinforced Polymer (CFRP) composites using 3D printing technology is a hot topic in the field of composite materials' research. Due to the continuity and infusibility of the long carbon fiber, a series of problems such as loosening of fiber, breakage, and nozzle clogging occurred in the printing process, which result in poor surface quality and performance in the printed product. This paper aims to solve these problems based on the researches and optimizations of three-dimensional printing technology for continuous CFRP composite components. Firstly, the coupling mechanism of continuous fiber and resin polymer in the flow path of nozzle is analyzed, the finite element simulation models of flow field and temperature field of CFRP three-dimensional printing are established by using ANSYS CFX software, and the coupling characteristics and interface performance in the printing process are studied. Then, based on the results of simulation analysis, a modification method of the surface coating film is applied, and a special modification solution is configured to modify the surface of the carbon fiber so as to increase its strength and bondability with the molten resin. Finally, the mechanical structure of the three-dimensional printing system of continuous CFRP components is designed to achieve the synchronization of printing and fiber modification. Considering the continuity of continuous carbon fiber, this paper proposed a new method of printing path design called "unicursal" for continuous CFRP parts, that is, when designing and planning a three-dimensional print path, it ensured that there is no interruption in the printing process, so as to achieve carbon fiber continuity in composite parts. The reliability and superiority of the printing system designed in this paper are confirmed by printing of the composite parts.

1 Introduction

Composite material is a new type of material synthesized from two or more materials of different properties by physical or chemical methods. Composite materials combine the advantages of different materials in terms of performance, so that the overall performance of the composite material is better than a single material to meet a variety of different needs. Continuous carbon fiber-reinforced resin-based composites are one of the most widely used materials in today's industrial fields such as aerospace and automotive manufacturing. The manufacturing process of the traditional Continuous CFRP component mainly includes three steps: First, the prepreg is prepared by a deposition method or a dipping method; then a simple-shaped composite material part is manufactured through a process of laying, pultrusion, and winding; Finally, continuous CFRP members are prepared by machining assembly, cementation and other processes[1]. The manufacturing process of this method has many disadvantages. For example, the process is complicated, secondary processing is required, and the production cycle is long; most of the production requires a mold and the cost is high; the processes such as cementing or assembly are required, and the complexity of the manufacturing process is limited.

Three-dimensional printing (also known as 3D printing, rapid prototyping, additive manufacturing, etc.) is considered to be a major breakthrough in manufacturing technology in the past 20 years, and is also known by many domestic and foreign media as a representative technology of the "third industrial revolution". Under the control of a computer, components of any complex shape can be rapidly fabricated through accurate 3D accumulation of materials based on data such as computer aided design (CAD) models or computed tomography (CT) scans of objects. Undoubtedly, 3D printing technology (Three dimension, 3D) opens up a whole new idea for the manufacture of composite materials. Compared with traditional manufacturing processes, 3D printing technology has the advantages of low cost, high material utilization, and simple process[2]. With the advent of the 3D printing process and its rapid development, it provides an effective technical approach for the low-cost rapid manufacturing of continuous CFRP components, making it possible to integrate the rapid manufacturing of CFRP components with complex structures[3]. Improving the applicability of 3D printing technology in the manufacture of composite materials has important engineering significance for promoting the cost-effective manufacture of continuous fiber-reinforced resin-based composite products.

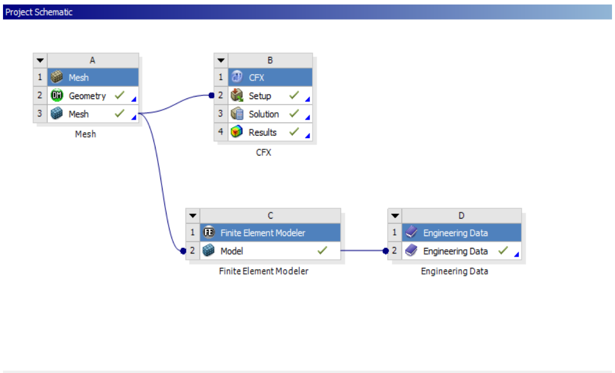
In the 3D printing process of continuous fiber reinforced resin composites,because of the continuous carbon fiber does not melt at a high temperature and its own strength is insufficient, it often causes the problems of continuous fiber breakage and fiber blocking of the nozzle in the three-dimensional printing, resulting in the result that the surface of the product is not smooth, the precision is low, and the component cannot be formed[4-6]. Therefore, how to improve the practicality of 3D printing equipment in continuous CFRP component manufacturing has become a hot topic in the current research field.

This article mainly focuses on the above issues, researches and optimizes the three-dimensional printing technology of continuous CFRP composite components. Firstly, the coupling mechanism of continuous fiber and resin polymer in the flow path of nozzle is analyzed, and the finite element simulation model of flow field and temperature field of CFRP three-dimensional printing is established by using ANSYS CFX software. The heterogeneous coupling characteristics and interface of the composite material in the printing process are discussed. Then, based on the results of simulation analysis, a modification method of the surface coating film is applied, and a special modification solution is configured to modify the surface of the carbon fiber so as to increase its strength and bondability with the molten resin[7]. Finally, the mechanical structure of the three-dimensional printing system of continuous CFRP components is designed to achieve the synchronization of printing and fiber modification. Taking into account the continuity of continuous carbon fiber, this article proposes a new type of "unicursal" print path for continuous CFRP components, that is, when planning a three-dimensional print path, it is allowed to have no interruption in the printing process, so as to ensure the composite Continuity of Carbon Fibers in Molded Parts[8]. the three-dimensional printing of continuous CFRP components proves the effectiveness of the system designed in this paper.

2 Simulation

2.1 Model establishment

ANSYS CFX is a high-performance computational fluid dynamics (CFD) software that provides fast, robust, reliable and accurate solutions for a wide range of CFD and multiphysics applications.After meshing, it can be imported into the CFX module of the ANSYS workbench for analysis. Save it as "mesh" format and import it into CFX as shown in Figure 1(a). Then click on "setup" to start the calculation process.



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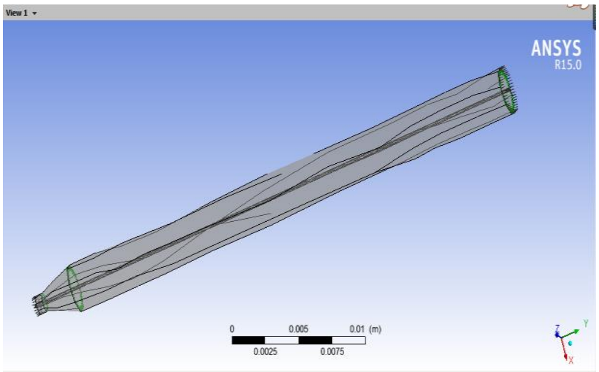

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Figure 1. CFX module interface (a)and Model after importing CFX(b)

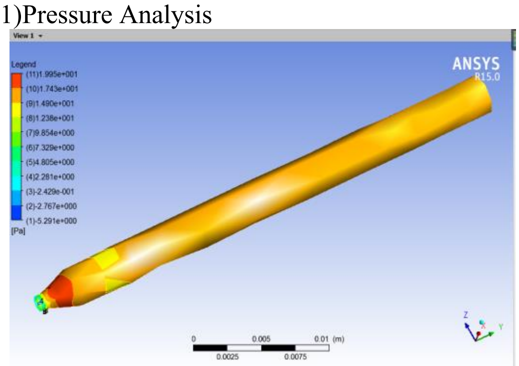
The imported model is shown in Figure.1(b). After determining the model is correct, set the boundary conditions. According to the actual situation, set the type of fluid, the material of the fluid, the material of the outer wall of the nozzle, and the inlet and outlet flow speeds.

2.2 Simulation results

Click ‘solution’ for iterative calculations. After the calculation is completed, enter ‘result’ to analyze the result.

After the calculation is completed, select post-processing. In the post-processing model, there are multiple reference indicators. However, the focus of analysis in this paper should be close to the actual production. When the fluid rotates, it takes into account the viscosity of the material and the pressure of the fluid on the carbon fiber. Effects, etc. The selected reference indexes are velocity distribution and pressure distribution.

(1)Pressure Analysis



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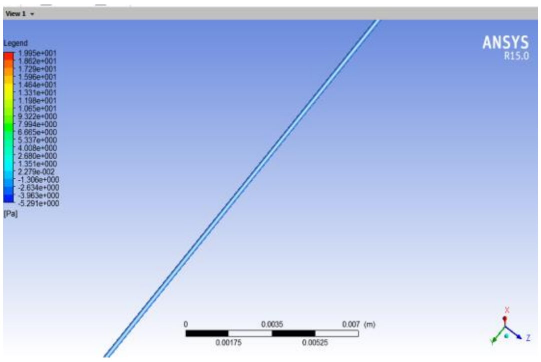

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Figure 2. Partial pressure cloud image of nozzle(a) and Carbon fiber pressure cloud(b)

It can be seen from Figure 2(a) that the pressure on the entire wall surface is relatively uniform and less than the pressure at the nozzle, and the pressure at the nozzle presents a tendency of rising first and then decreasing, and the pressure closer to the air space is smaller. Carbon fiber is driven by the flow of molten resin to move it outward. Therefore, the pressure of the fluid on it must be considered.

Figure 2(b)shows the carbon fiber surface pressure cloud. It can be seen from the figure that the carbon fiber is surrounded by the fluid and the pressure received is uniform and small, which meets the actual needs.

(2)Speed analysis

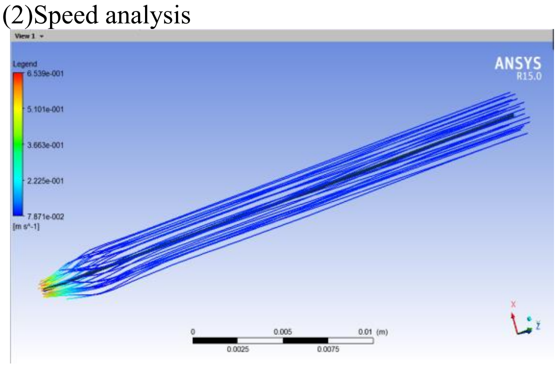


Figure 3. Velocity streamline of Fluid

Another reaction indicator of the flow field is the fluid trace. Changes in the fluid trace can reflect changes in the distribution and trends of fluid flow. That is, it can reflect the actual liquid flow in the nozzle and thus has a reference effect on the change of the flow field.

As can be seen from Fig. 4, the viscosity of the molten resin causes the flow rate of the liquid to decrease and maintains a uniform velocity in the nozzle, and the speed increases when the fluid reaches the nozzle head.In actual operation, the simulation data can be compared to determine whether the fluid inside the nozzle is blocked.

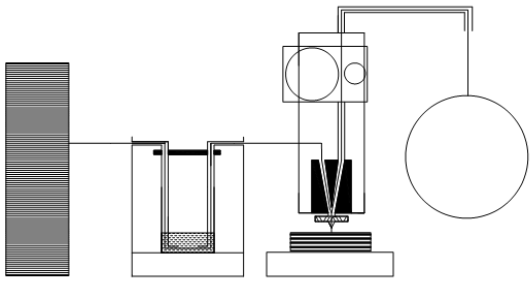
3 Process design

From the simulation results, it can be seen that in the three-dimensional printing process of the continuous CFRP component, although the force around the carbon fiber is even, the force is very small. This may be such that the carbon fiber cannot be extruded from the nozzle together with the molten resin during printing

In order to overcome the defects in the existing 3D printing technology of continuous CFRP components, this paper will design a 3D printing method for continuous CFRP components that can be simultaneously modified and printed based on the simulation results.

3.1 Process principle

The feature of this process is that during the printing process, the continuous carbon fiber is infiltrated with the modifying solution before reaching the print head, so that the surface properties of the continuous carbon fiber are improved, the continuous carbon fiber is not easily broken and can be better combined with the molten liquid resin.



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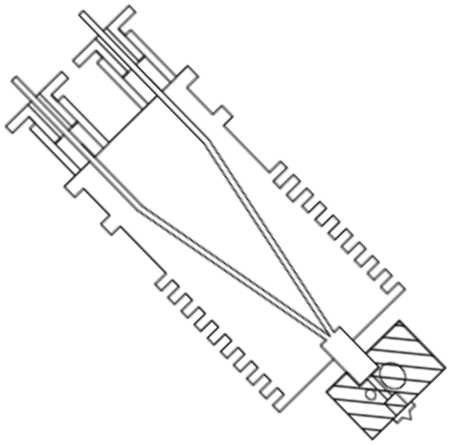

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Figure. 4 Process principle (a) and print head design (b)

As shown in Figure 4(a). The process uses thermoplastic resin and continuous fiber as the printing material, and the two materials respectively enter the print head from the left and right two entrances of the print head (the internal structure of the print head is shown in Figure 4(b)).The continuous carbon fiber is infiltrated and modified by the modifying solution before entering the print head, and then the modified carbon fiber enters the heating chamber to be combined with the melted resin and is printed out. Finally, the modification of carbon fiber and three-dimensional printing are carried out simultaneously to realize the integration of composite material preparation and forming. The thermoplastic resins that can be used in this process include PLA, ABS and nylon, and the continuous fibers include carbon fiber and glass fiber.

3.2 Preparation of modified solution

The method of surface modification of carbon fiber used in the three-dimensional printing of continuous CFRP components designed in this paper is a modification method by coating a film on the surface.

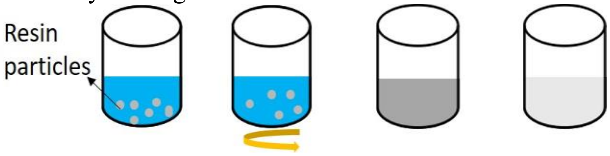

Figure.5 process of modifying the solution configuration

As shown in Figure 5, the configuration of the modified solution is divided into the following steps:

1. Pour Dichloromethane into a beaker and add resin particles (PLA or ABS) with a volume fraction of 5% to 10%. Stir with a glass rod.
2. Place the beaker on a magnetic stirrer, set the rotation speed to 3000 or more, set the temperature to room temperature, and set the stirring time to half an hour. Wait until the stirring is completed.
3. The stirred solution is filtered through a gauze to obtain a clear, viscous resin-dichloromethane solution, which is the modified solution.

After the carbon fiber is infiltrated with the modified solution, it is equivalent to the surface of the carbon fiber wrapped in a layer of resin, so the combination of the resin with the melted resin will be greatly improved, and it will be easier to move with the flow of the resin during the printing process.The methylene chloride itself is highly viscous. After the carbon fiber is infiltrated, the internal carbon fiber filaments will be more firmly bonded and will not be easily dispersed in the three-dimensional printing process. improve the quality of printed CFRO components Ultimately.

4 path planning and printing

4.1 Continuous 3D printing path planning

This paper studies the printing path planning of 3D printing process based on continuous CFRP components. Unlike traditional printing paths, the 3D printing path satisfies some new requirements due to the continuity of the carbon fibers in the continuous CFRP components. Studies have shown that the printed path not only affects the final molding quality of the composite structure, but also that the fiber orientation in the composite material has a great influence on the performance of the final molded part. Therefore, how to design the structural form of the printing member structure and the design of the internal continuous fiber to control the print path of the fiber is the key to realize the three-dimensional printing manufacturing of the high-performance continuous CFRP member. For this reason, this article has designed a " unicursal" continuous print path setting.

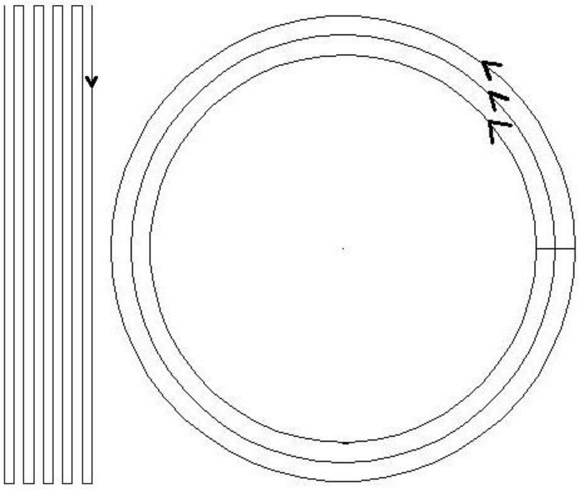

Figure. 6 Continuous 3D Print Path Planning

In the case of a three-dimensional printing of a rectangular continuous CFRP member, the print path is as shown in Figure 6. The print head moves in accordance with the uninterrupted "unicursal" path. After printing a layer, the next layer is reversed. The direction continues to print, and the final layers are stacked. The print path setting of the closed circular continuous CFRP member is as shown in Figure 6. Let the print path be printed from the inside outward or from the outside to the inside, and set a cut-in point after printing a closed loop to print the next Closed loop, the last layer of stacked forming.

4.1 Process validation

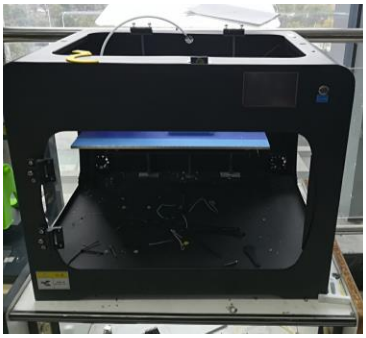

Figure 7. Continuous CFRP component 3D printing equipment

In order to verify the feasibility of the proposed process, this paper preliminarily completed the fabrication of continuous CFRP component 3D printing equipment based on the three-dimensional printing principle of FDM and the simultaneous modification and printing process of continuous CFRP components, as shown in Figure 7.

Figure 8. Continuous CFRP rectangular member

In this paper, a rectangular continuous CFRP object is printed on the device according to the "unicursal" print path, as shown in Figure 8. As can be seen from the figure, the entire component surface is fairly flat and smooth. Inside the construction, continuous carbon fibers are uniformly distributed on each layer of the member and the carbon fibers are tightly bound to the resin. Continuous carbon fibers do not be broke apart during printing.

5 Conclusion

The 3D printing system of continuous CFRP components designed in this paper can effectively improve the surface properties of continuous carbon fibers in the threedimensional printing process, improve the combination of carbon fibers and melted resin, and make the continuous carbon fiber materials well wrapped with thermoplastic resin And make continuous carbon fiber not easy to break in the printing process. Through the " unicursal" print path planning, continuous carbon fibers will not break due to discontinuities in the path. The 3D printing continuous CFRP component is prone to defects such as burrs, fiber breakage, and poor adhesion between the resin and continuous carbon fiber, which greatly improves the three-dimensional printing quality of the continuous CFRP component.

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