Ultrasound-assisted 3D printing platform and method capable of flexibly adjusting layer thickness and rotation angle

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Abstract. The technology of arranging particles by ultrasound has matured. In recent years, this technology has been used as a basis for arranging particles in a photocurable resin for stereolithography (SL). In order to process the resin doped with particles to obtain a variety of particle arrangement patterns, most of the previous work chose to use different polygonal containers to obtain single-layer fiber angles. In this adjustment mode, the selectivity of the fiber angle is very poor, usually 45°, 90° and other common angles. In this work, we designed and manufactured a new ultrasound-assisted 3D printing platform that can flexibly adjust the thickness of the sandwich and the rotation angle of the sandwich. We will introduce the basic working principle and matching usage of the device, and show some basic print samples.

1. Introduction

The matrix doped with particles with specific patterns can make engineering materials exhibit unique mechanical, electrical, thermal, acoustic and electromagnetic properties. It depends on the material characteristics, geometry and arrangement of the doped particles [1]. At present, in order to achieve 3D printing of short fiber reinforced composite materials, in addition to a wide range of direct printing and molding methods, there are usually the following auxiliary methods to choose from: shear force [2,3], electric field [4,5], magnetic field [6-8] and acoustic wave field [9-13]. Among them, the shear assist mode is to force the particles to complete the arrangement by using the shearing action of the nozzle on the molten metal wire or fluid. Liquid mixed with particles. The advantage is that a higher fiber volume fraction can be achieved, but the printing quality depends on the particle/fiber distribution of the premix. The magnetic field or electric field assist method can be used to drive these charged or magnetic particles to complete the desired pattern. Both methods have performance requirements for the particles.

The use of ultrasound-assisted methods to assemble particles/fibers can realize the layout of the entire area without requiring the shape and properties of the particles/fibers. When arranging one-dimensional linear and two-dimensional array patterns, the ultrasound-assisted method is faster and more accurate. At the same time, the battery can be operated without damaging the battery. These advantages are not available in other auxiliary methods. Therefore, it is necessary to research and develop this technology, including exploring the principle of self-assembly of one-dimensional linear or two-dimensional array patterns, sample testing and practical applications.

In the research of others, polygonal resin containers are basically used, including quadrilateral, hexagonal and octagonal, to obtain different single-layer pattern angles. The pattern fiber angle of the...
single-layer particle arrangement that can be obtained in this way is definite and only a few angles. The flexibly adjustable inter-layer angle can make the particle arrangement pattern inside the printed part more diversified, instead of just a few definite angles, such as 45°, 90°. It is very helpful to test the performance changes of the printed parts with the change of the angle between layers, including mechanical properties, electrical properties, etc. Therefore, we decided to design a feasible device to achieve possible continuous angle changes and variable inter-layer thickness.

2. Design and Fabrication

There are very few reports on ultrasound-assisted 3D printing equipment. Most research work is still at the stage of single-layer particle arrangement patterns. There are still many unknown problems in multi-layer printing. From the experience of single-layer printing, we need a piezoelectric transducer (PZT) and a glass reflector placed opposite it to generate a bulk standing wave field, which also requires a supporting signal generator and power amplifier. When the particle pattern is arranged to achieve the desired effect, we need to use a suitable UV light source (usually 365nm or 405nm) to cure the single-layer sample. This curing process can be full-area or selective, and it depends on your specific needs. The next step is multi-layer printing stacked layer by layer, which requires a movement in the Z direction. The thickness and curing time of each layer, and the smoothness of operation need to be considered. Finally, we need to rotate the resin container so that each layer can obtain different fiber angles (in the actual test, we used light-curable resin doped with carbon fiber) separately while keeping the PZT position and parameters unchanged.
chose a 405nm ultraviolet light source (70W), covering with LCD panel, as selective light transmission. The light source is placed in the casing of 3D printing, which ensures its stable placement and keeps good heat dissipation. The z-axis direction of photocuring technologies can be divided into two schemes: the desktop type is with the light source below, and it is molded and pulled up through the window and the release film; Industrial large-scale ones are all above the light source, and the molding sinks below the liquid surface, so the liquid surface does not need a release film. Desktop-level printing can meet the experimental requirements, as shown in Figure 2, which shows the composition of the whole experimental platform. Different from previous work, we use the rotating platform to drive the resin container to rotate, which can bring flexible change of rotation angle between layers.

3. Printing process and discussion

The resin container was filled with photosensitive resin doped with carbon fiber, and carbon fiber did not need any marks such as conductivity or magnetism. The samples of single-layer and multi-layer materials are composed of 0.5wt% carbon fiber, with length \(l = 100\ \mu\text{m}\) and diameter \(d = 10\ \mu\text{m}\), which are dispersed in liquid light-curable resin with viscosity of 100 Pa·s for 15 min at 600 rpm by magnetic stirrer. The mixed solution was taken out with a pipette and dropped into a quartz resin container.

The next thing to do is to connect the piezoelectric transducer (PZT), adjust the output frequency and amplitude from the signal generator, and apply it to the PZT through the power amplifier. Under the excitation of a sinusoidal signal, PZT can generate ultrasonic waves through the inverse piezoelectric effect. This is a kind of bulk acoustic wave, which acts on the mixed liquid and propagates to the glass reflector. After reflection, a standing wave field is generated. In the mixed liquid, the carbon fibers are constrained at the nodes to form a single-layer particle arrangement pattern.

Here we give the result of the total sound pressure field simulated by Comsol multiphysics 5.3, as shown in Figure 3. We have established a two-dimensional sound field simulation model according to the actual size, which includes PZT, reflector and mixed liquid area. The material of PZT is defined as PZT8, and its two electrode surfaces are applied with a frequency of 1.86MHz and a voltage of 150V. After defining various other necessary parameters, the simulation can be performed to obtain the sound pressure distribution in the mixed liquid area. Through observation, it can be seen that the sound pressure field is basically a regular and periodic distribution in a two-dimensional area. When the particles are placed in this sound pressure field, the particles will be driven by the sound radiation force in the sound pressure field to squeeze at the nodes, forming the example pattern we need. The spacing between the lines formed by the particles can be changed by adjusting the frequency, and the degree of aggregation of the particles can be changed by adjusting the voltage value.

![Simulation results of the total sound pressure field.](image)

Then we need to turn on the LCD screen and UV light source to cure the arranged patterns. This process takes about 1 minute, depending on the resin used and the concentration of doped carbon fiber.
In the case of only a single layer of samples, the printing process is over here. If you need a multi-layer sample, you need to raise the Z axis, the pattern will stick to the upper printing table instead of the quartz container due to the release film. Rotate or not rotate the quartz container (depending on the desired layer change), again use a pipette to drop the mixture into the quartz container, and repeat the previous single-layer printing process. When this cycle continues, you will eventually get a sample of customized fiber angle combinations.

Figure 4. The actual printed single-layer sample display.

Judging from the simple samples shown above, our platform can effectively complete the process of single-layer particle arranging patterns, and finally a single-layer or multi-layer sample with clear contours can be obtained after selective curing. Through adjustments, the printing of multi-layer samples has also been completed, which is good news for ultrasound-assisted 3D printing. This means that we can use this platform to perform mechanical tests on samples with a single-layer particle arrangement pattern. For multilayer samples, we can also customize the printing, including customized flexible printing layer thickness and interlayer rotation angle. However, our platform is still in the preliminary testing stage. There are many aspects that are inconsistent with the original intention of the design, such as the way of rotation. When designing, we want to bind the platform's UV light source, LCD and quartz container into a whole, so that they can rotate together. But in reality, our functional requirement is to make the LCD fixed, and the quartz container needs to be rotated to achieve the goal of continuous angle changes between layers. In addition, we also need to improve the bonding method of the release film, which is related to the quality of the molding including size and shape.

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