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Highly removable water support for Stereolithography

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ABSTRACT

Current stereolithography (SL) technology can print there-dimensional (3D) objects with high precision and fast speed. However, for a complex computer-aided design (CAD) model, the fabricated structures have a significant amount of additional support structures that are required in order to ensure the model can be fabricated. However, these support structures may be difficult to remove. Even worse, the removal of the support structures may cause unexpected damage to delicate features and leave undesired surface marks. Although some special materials have been utilized in support structures such as water-soluble materials for the fused deposition modeling (FDM) process and wax for the multi-jet modeling (MJM) process, such support materials have not been available for the SL process. In this paper, a novel SL process using highly removable and widely available water as supports is presented. The process uses solid ice to surround the built parts in the layer-by-layer fabrication process. A cooling device is used to freeze the water into ice for each layer. The photocurable resin is spread on ice surface and then solidified by a projection image. Accordingly, a complex 3D object can be fabricated without using traditional support structures. After the fabrication process, the additional ice structure can easily be removed leaving no undesired marks on the bottom surfaces. Two test cases are presented to show the effectiveness of the presented highly removable water support method.

1. Introduction

In ancient time, some types of trees can produce resin. The abnormal development of resin in living trees can result in the formation of amber. Amber is fossilized tree resin, which has been appreciated for its color and natural beauty for a long time. Amber sometimes contains animal and plant material as inclusions, especially when the resin dropped onto the ground. Hence an insect may be surrounded by this unexpected tree resin. Over time, the resin may survive long enough to become amber and the insect pose inside will last forever [1]. Inspired by this phenomenon in nature, we hope to apply the amber mechanism to additive manufacturing (AM) process for support structures.

Layer-based AM processes, such as stereolithography (SL) [2], can directly fabricate parts from CAD models. As a direct digital manufacturing approach, current AM processes can effectively fabricate extremely complex three-dimensional (3D) shapes that used to be impossible to be made [3]. However, for most CAD models with complex geometries, extra support structures are needed in the layer-based fabrication process [4,5]. For the fused deposition modeling (FDM) process, some special water-soluble materials have been invented to print support structures by choosing multi-material printing mode [6]; people also used wax material as the support structures in the multi-jet modeling (MJM) process [7]. Consequently, removing support structures becomes easier and it is less likely to damage the built parts when removing the support structures. However, for the SL process, the building process uses a liquid resin tank. Hence, the SL process based on multi-materials has always been difficult although some previous efforts have been made to achieve multi-material SL process [8–11].

We are motivated to address this critical challenge for the SL process. In this research, we investigate the fabrication process based on water/ice for the mask-image-projection based stereolithography (MIP-SL) [12,13]. In the MIP-SL process, a CAD model is sliced into a set of two-dimensional (2D) layers with a given layer thickness. Each layer is prepared individually by projecting the masked image of the layer onto the liquid resin surface. After the ultraviolet (UV) light exposure, liquid resin is solidified into the sliced layer shape that attaches to the previous layers. In order to add water support structure, we investigate the top-down projection system in the MIP-SL process. A critical thermoelectric device [14,15] is selected and applied in the MIP-SL system to freeze the water into ice.

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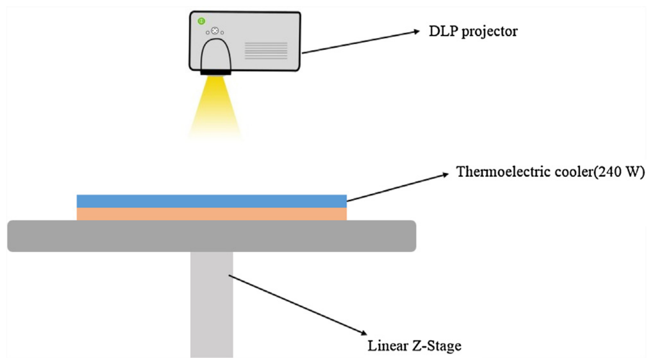

Fig. 1. Building platform for the process.

1.1. Limitations of traditional support structures for SL process

In the traditional SL process, the additional support structures will waste a lot of extra materials since they will be removed after finishing the building process. In addition, it is time-consuming for users to manually remove all the support structures. Even worse, the removal of the support structures may cause unexpected damage to delicate features of the built objects, resulting in undesired surface finish. Consequently, the added support structures will dramatically increase the building time and cost in addition to the tedious post-processing process. For some special applications, it may even be impossible to remove the support structures that are difficult to access, and support structures may be required in some critical areas that are not allowed to have them.

1.2. Contributions

To address the limitations of traditional support structures in the SL process, we present a novel approach to build water support that will surround the built objects in each layer. Our approach is a multi-material printing method based on a top-down projection system. We address the related challenges in controlling the surface level of ice due to the volumetric expansion when water converts to ice and other considerations. By optimizing the process settings, we have designed test cases to illustrate that our approach is able to fabricate critical components with delicate features. Consequently, the developed water-support-based MIP-SL process can fabricate highly complex parts which are previously impossible for the SL process.

2. Water support building process study

In this research, a top-down MIP-SL process is applied for building water support structures. However, unlike the traditional top-down SL process based on free surface, the top resin surface is constrained by a Teflon-coated transparent glass in our approach. In addition, instead of using a tank to store liquid resin, we adopt a material spreading and removing method to achieve the desired water support building process. Consequently, the final building part will be surrounded by solid ice similar to Amber, instead of fixing by additional supports that are merged inside liquid resin tank.

2.1. Building platform design

As shown in Fig. 1, a thermoelectric cooler is mounted on a linear Z-stage, which can move up and down along the Z direction. The thermoelectric cooler in our setup is used as the building platform where the built layers will be grown from. When a positive voltage is applied to the thermoelectric cooler, the temperature on the top surface will dramatically decrease to below zero degrees Celsius just in seconds. Thus, it can maintain a continued low temperature environment to ensure the success of the building process. Consequently, the thermoelectric cooler that is used as a building platform will always be kept on during the entire building process until all the layers have been built.

2.2. Building process illustration

A water dispenser is mounted on the front of tool A as shown in Fig. 2a. Adjusting the linear Z-stage to form a 100 μm gap between the top and bottom cooler, then we move tool A to spread one layer of water in a given thickness on the top surface of the bottom cooler. Due to the surface tension, water will be constrained in the gap between the two coolers. After turning on both of the two coolers, the water in the gap will be converted into ice in several seconds as shown in Fig. 2b. The bottom surface of the top cooler is coated with a piece of Teflon film in order to decrease its surface friction such that the top cooler can easily be separated from the ice below. The reason for building the first ice layer is for the easy separation of the part after the entire building process has been finished, i.e. the built object can easily be taken away from the building platform by simply melting the base ice layer. No extra effort is required. It will significantly prevent the built objects from being damaged by using a scraper in the traditional approach.

As shown in Fig. 2c, another tool B will move towards the building platform right after moving away from tool A. Similar to tool A, a resin dispenser is mounted on the front of tool B, which will be used to spread one-layer liquid resin on previously solidified layer surface with a desired layer thickness. After that, a pattern image is projected on the resin surface through a transparent glass. The exposure time for each layer in our setup is ~20 s.

A resin vacuum is mounted on the rear side of tool B. After the exposure time as shown in Fig. 2d, tool B is moved away. During the movement of tool B, the mounted resin vacuum will be turned on to suck out all the unsolidified residual liquid resin from the building platform, leaving only one layer of solidified resin pattern. After that, tool A will move towards the building platform again as shown in Fig. 2e. It will spread water to fill the empty slots in the previous layer and freeze them to ice. Consequently, we will get a layer that consists of both the solidified resin pattern and solidified ice. Then by repeating the process from Fig. 2c–e, another patterned layer as shown in Fig. 2g can be fabricated.

The flow chart shown in Fig. 3 briefly describes the water support building process.

2.3. A proof of concept

As shown in Fig. 4a, a simple CAD model was designed to verify the concept of the presented building process. Unlike the traditional SL process, which will require a support structure as shown in Fig. 4b for this CAD model, to ensure the success of the building process, we used the aforementioned process to directly fabricate the designed CAD model without adding any support structures. Instead, ice support similar to amber is added in the building process as shown in Fig. 4d. After finishing the building process, the surrounded ice support was then melted away as shown in Fig. 4e–f. Consequently, the desired part can be fabricated without any undesired surface marks as shown in Fig. 4g–i.

2.4. Study of the impact of ice on dimensional accuracy

The presented ice support building process requires the built part to be embedded in ice. Since water expands when it freezes, a study of the dimensional accuracy of a built part has been performed to understand the impact of ice and low temperature on