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Design of a Self-adjusted Mechanism in Combination with Passive Peeling for Effective Separation used in Digital Light Processing (DLP) 3D printing

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1、Introduction

Additive manufacturing, also called 3D printing, is a computer-controlled process to synthesize a three-dimension object by stacking materials layer by layer. This process starts from creating a digital three-dimension model of the object. Then the printing path of each layer of the object is layout by the computer software. Finally a stacking technology is selected to complete the production. Recently, the Economist Report has regarded additive manufacturing as an important technology in the third industrial revolution as internet of things (ICT), artificial intelligence (AI) and biological technology [1]. Nowadays additive manufacturing has been commonly utilized in prototyping, art, automotive, aviation and medical industries [2].

In additive manufacturing, several different additive processes have been developed with corresponding materials used. For example, thermal plastic is utilized in fused deposition modeling. Photopolymer is used in light polymerization. Metal or ceramic powder is used in selective laser sintering. Fused deposition modeling is the most popular process used currently because of its cheaper cost and convenience to operate. However, frequent clogging in the nozzle of machine and rough surface of the printed object are the two major drawbacks of this process. If these drawbacks are needed to be avoided, the process of light polymerization is preferred because the printed object by light polymerization has higher mechanical strength and finer surface.

The process of light polymerization includes two technologies, stereolithography (SLA) and digital light processing (DLP). Both of these technologies solidify the object by light exposure. But different light sources are used: SLA uses laser point light and DLP uses projector surface light. Compared with SLA, the object surface fineness of DLP is worse. Nevertheless, DLP still has a higher developmental potential since the production is faster and the print size is not limited by the light path.

There are two common methods, top-down (free-surface) and bottom-up (constrain-surface) in material filling of light polymerization process. The differences lie in polymer curing and build orientation. In the top-down method, the liquid material is solidified by light exposure and then adhered to the platform. Afterwards, the platform is moved down and the surface of first layer is recoated with liquid material. The process will be repeated until the fabrication of molding is completed. In the bottom-up method, the platform is moved up instead after each layer is fabricated. When these two methods are compared, bottom-up method is more common because of higher material filling rate and vertical resolution [4].

The separation behavior between the solidified layer and platform is an important issue in the bottom-up method of DLP. If the separation force exceeds too much, the curing part may directly break; if the separation force is not enough, the curing part can't successfully be separated and then it negatively influences the next printing layer. There are some new technologies developed to improve this issue but there is still no perfect solution [5-6]. This paper will firstly discuss the separation force of the bottom-up method in DLP by developing a different 2D modeling of separation mechanism and then design a prototype to test based on the best analysis result.

2、Design Concept

It is necessary to understand the cohesive behavior and corresponding physical parameters between wo layers of materials before we develop the analysis model of separation force. For the cohesive behavior, it is hard to directly calculate based on the formulation of materials or mechanical testing by the previous research results [6]. From a simple geometric point of view, the separation mechanism between two layers of materials in DLP can be explained similarly to the four stages of SLA in Fig 1 [6]. The solid layer and the platform are both dynamic during the whole separation process. In Fig 1 (a), the cured layer is sandwiched between the previously built layer and the top surface of the platform. When all parts start to move up, the platform begins to deform and then separation and fracture of the solidified layer occur initially at the contact edge of surface in Fig 3 (b). The separation propagates into interior area during the continuous moving up of the parts in Fig 3 (c). In Fig 3 (d), the separation is completed after the parts move up to an appropri ate distance.

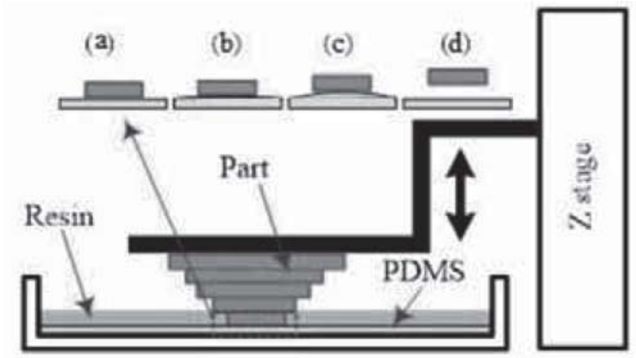

Fig 1. The separation process in bottom-up SLA [6].

The current mechanism for separating solid layer in DLP machine is shown as Model A and B in Fig 2. The platform (PDMS) is fixed in either sides (A) or all (B) and the solid layer (photoresin) moves up to separate from the platform. A modified mechanism which changes the fixation of platform is shown in the Model C of Fig 2. The platform is fixed only on one side and the other side is free to swing as the movement of cantilever beam. Different from type C, a spring component is added in the free side of the platform in type D.

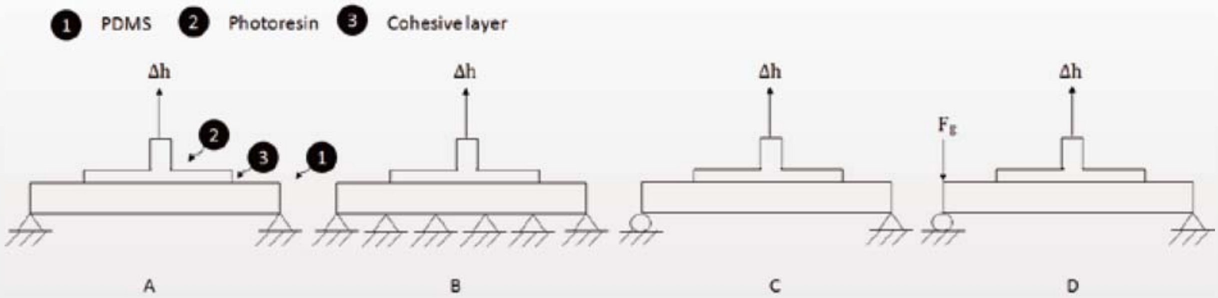

Fig 2. Four different models for analyzing the separation behavior [7].

Lin and Yang [7] have used computer software to analyze these four models and found that the separation stress main acts on the solid layer in Model A and B. The separation force increases when the contact area of surface increases. Separation failure will happen more frequently when using structurally weak material to print the solid layer with huge area. In Model C and D, the part of solid layer which is closer to the fixed side of the platform separates faster than the other part from the platform. In addition, the separation stress mainly acts on the platform. The shear force acted on the solid layer is also less significant. As a result, the success rate of separation increases and less time to start separation is spent. In Model D, separation of solid layer and inhibition of platform upward movement can happen at the same time by adding spring over the free side of platform. Moreover, the spring force is adjusted automatically by the extent of upward movement of the platform. Therefore, Model D should be the best model for separation of solid layer from the platform. A new 3D printing machine will be designed using Model D accordingly.

3、Technical Development

3-1 Design and Fabrication of a DLP Printer

Designing process of a DLP printer is consisted of a few main tasks, including framework, a light source, a movable driving system, a object plate, a resin tank, and a separation mechanism. Fig 3 shows the CAD model of entired design in this study, material of the framework is extruted aluminium with an area size of 30mm square. The full dimension of framework is 530mm height, 470mm length and 260mm width. Four anti-vibration feet are attached on the bottom corner. The designed size is for an enough space of the digital light projector, and a DLP projector BenQ MH684 with a Full-HD resolution (1920x1080), 3500 ANSI lumems, a 2D correction feature and a corner fit feature for image adjustments.

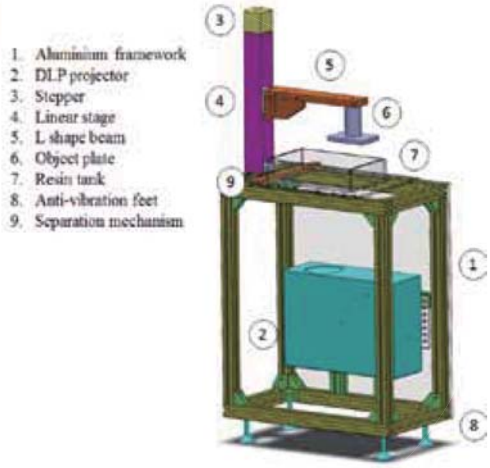

Fig 3. A CAD model of the fabrication.

The movable driving system is placed upright towards the framework, and consisted of a stepper motor for a vertical movement, which is connected to a linear stage. A lead screw and a linear guide are both used on linear stage to provide more accurate movement. And a cantilever beam (L-shape)is carried to mount an object plate for stereolithography processing. Object plates are used to bond with printed models, hence, the surface of object plates are often required higher roughness or honeycomb shape, as shown in Fig 4. Photonn liquid is filled in an acrylic resin tank. The acrylic resin tank can be purchased from market, there is a transparent FEP film on the bottom to provide an easier separation.

Fig 4. Object plates with different honeycomb pattern on surface.

To actuate the designed printer for automatic work, a power supplier, a control system and a control panel are required. The control system is equipped with an Arduino Mega 2560 control board, a motor shield board A4988 and a Ramp 1.4 motor controller. The communication in between firmware and control panel is using Arduino. In addition to activate the projector automatically, a RS232 cable line is wired from the projector to a computer so that the projector can be switched via a computer. Fig 5 shows the process of assembly.

Fig 5. Process of assembling an in-lab designed DLP printer.

3-2 Procedure of control

An entire stereolithography process can be divided into three stages: preparation, operation and post-processing. Point cloud models (.stl) are sliced into a sequence of masks-like images in a preparation stage. Then photon resin is filled into tank and ready for an operation. Before starting, the object plate is driven to be immersed into photon resin until a calibrated gap from bottom of a FEP film. During the process, the object plate is driven up to an input distance. Meanwhile, an adhesion force is therefore generated the bonding, as described in Fig 1. A separation is required by lifting height to at least break the adhesion, so that object plate can be driven back to height of the next layer. Such a separation movement is kept repeating every layers until the additive process is finished.

The flow chart shown in Fig 6 explains that the process requires two determination. Firstly, different mechanisms of separation during printing process can be selected, passive peeling and self-adjusted method. Secondly, a virtual validation is used to compare the printed model with the CAD model.

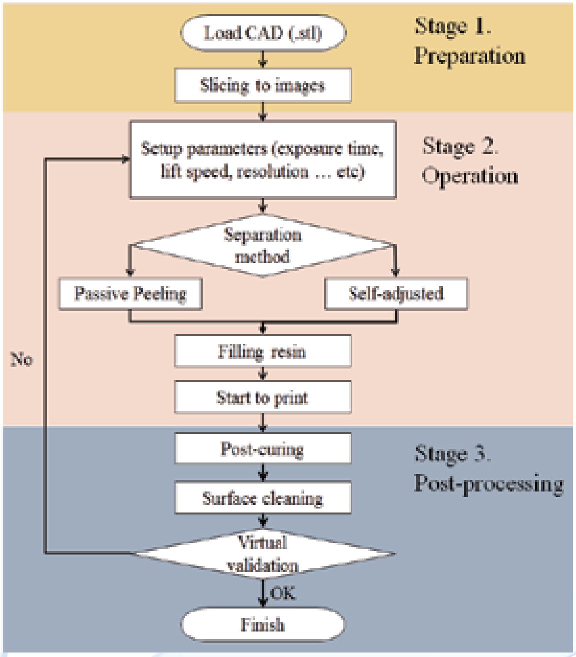

Fig 6. Flow chart of a printing process.

4、Technological Competitiveness

The scenario of separation happens in most stereolithography methods, such as SLA and DLP. The difficulty is to separate the printed model from resin tank instead of object plate. Previously, active separation method has been proposed to provide a force to pull straight up or down. In order to make an active mechanism, the contact surface of resin tank is kept flexible, called "flex vat". However, the direct force often causes badly force distribution and large break, a large contact area in particular.

A passive peeling mechanism is proposed by a company called Kudo3D Inc [8]. The concept is to fasten only a single side and allows the other side flexible. When resin tank suffers an adhesion to be pulled up, the tank gives a resistant force by its material force to detach from printed object, as shown in Fig 7 (A). However, acrylic plates are easily fatigued and bended after several cycles. Passive peeling method only relies on material strength.

Therefore, a self-adjusted mechanism is introduced in this study to provide a combination of passive and active peeling. The concept is to integrate a spring system on the other side to allow resin tank still move flexibly. A compression force gives a resistant force to against adhesion when resin tank is pulled up. If adhesion is stronger, a larger compression is given by compressed distance. In other words, a little compression is required if adhesion is small. And maximum giving force can be adjusted by changing a spring to higher spring constant. The self-adjusted mechanism can give a continuous force to provide more steady printing, resulting in accuracy and quality. The processing duration can also be optimised to be shorter.

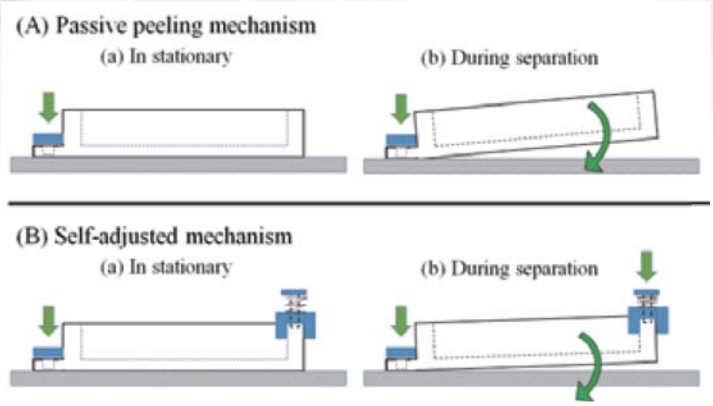

Fig 7. 2D Schematic diagram of (A) Passive peeling mechanism and (B) Self-adjusted mechanism.

5、R&D Result

The function of stereolithography processing can be seen in Fig 8 that a printed model is in the middle of exposure period and coming out from liquid typed photon resin.

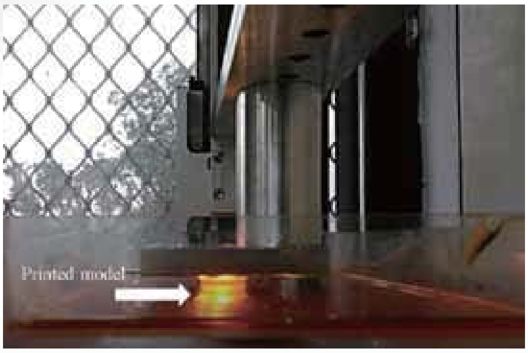

Fig 8. A printed model is come out of photon resin.

In order to investigate the performance and difference between passive peeling mechanism and self-adjusted mechanism, tests have been done with regard to its dimension of printed objects. The experience shows that passive peeling mechanism is capable to print small objects. This can be explained that nowadays DLP printers are very popular for printing jewellery. However, when the size of objects are increased, separation becomes more difficult. For example, Fig 9 shows a successful case study of printing a dental model with the self-adjusted mechanism. Before the self-adjusted mechanism is applied, very common issue is broken printing either on its surface or entire body.

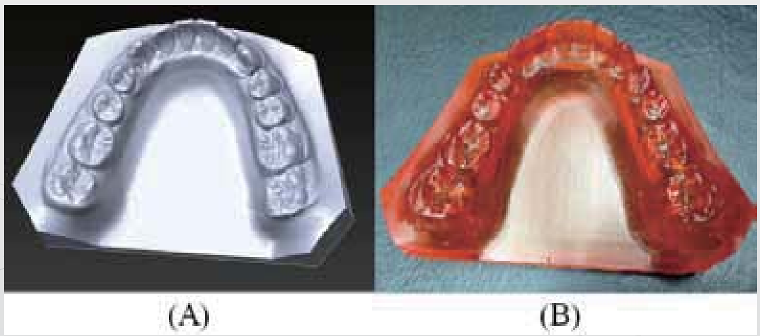

Fig 9. (A) a meshed CAD dental model from reverse engineering scan (B) a printed dental model without broken pieces.