Journal of Materials Processing Technology 243 (2017) 184–196

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Tilting separation analysis of bottom-up mask projection stereolithography based on cohesive zone model

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ARTICLE INFO

Article history:
Received 28 July 2016
Received in revised form
12 November 2016
Accepted 19 December 2016
Available online 21 December 2016

Keywords:
Additive manufacturing
Bottom-up mask projection stereolithography
Tilting separation
Cohesive zone model
Pulling-up separation
Separation force

ABSTRACT

Compared with top-down stereolithography, bottom-up mask projection stereolithography can reduce the start filling volume of vat and is able to build components with high-viscosity materials. For general photosensitive materials, a separation process is required to detach the cured layer from the resin vat surface in order to accomplish the fabrication of current layer. The separation process can be achieved without damaging the part by utilizing appropriate platform motions including pulling-up, tilting and shearing, and covering inert film on the vat surface. The tilting separation is used in both industrial and academic area. However, there is a limited corresponding study compared with pulling-up separation. The mechanism of tilting separation and its effects on separation force and fabrication process are not clear. In this paper, an analytical model based on cohesive zone model was formed and a specialized experimental system was built. Experimental studies on the tilting effects on cohesive stiffness and fracture energy were conducted by collecting and analyzing separation force data. The results showed that changing exposure area function or the part fabrication orientation changed the cohesive stiffness, and increasing tilting separation velocity caused different increase in fracture energy when using different inert films. The results of this investigation can be used to choose the reasonable platform motion and process parameters by considering the part geometry and the characteristics of both inert film and materials.

1. Introduction

Stereolithography is the first additive manufacturing (AM) technology that utilizes photopolymerization process to fabricate three dimensional objects. The scanning laser is used to cure photosensitive resin in a vat line by line and achieves high dimensional accuracy of part (Hull, 1986). Instead of using laser, mask projection stereolithography (MPSL) uses a pattern generator such as digital mirror device (DMD) to dynamically generate mask to cure a whole layer once (Choi et al., 2009) or generate masks to cure a layer in a scanning manner (Emami et al., 2015).

The bottom-up MPSL creates a constrained liquid layer between previously cured part and the vat surface before each curing procedure. The constrained liquid layer is then selectively cured according to the mask shape during curing procedure. Compared with top-down stereolithography, several advantages can be obtained by applying bottom-up MPSL (Fig. 1). The vertical direction curling of cured part that occurs in top-down stereolithography (Xu and Chen, 2014) can be reduced since the photopolymerization of bottom-up MPSL is reacted in a constrained area (Huang and Lan, 2006). The part fabrication with high-viscosity (Felzmann et al., 2012) materials is achieved because the recoating step (Renap and Kruth, 1995) is simplified. Only small amount of material is needed to start the fabrication since there is no need to maintain a whole tank of material (Zhou et al., 2013).

The curing process leads to adhesion at two interfaces of the constrained layer, as shown in Fig. 2(a). In order to proceed the whole fabrication process, the cured layer should be separated from the vat surface. Therefore, the force needed to separate the lower interface should be smaller than the force needed of the upper interface; otherwise, the part will be broken, as show in Fig. 2(b). During the whole process of part fabrication, it is necessary to ensure that each separation is successfully accomplished, which becomes a unique problem of bottom-up MPSL.

Different motions of the platform can be used to achieve separation, including pulling-up, tilting and shearing (Fig. 3). Most of industrial bottom-up MPSL machines use pulling-up as the separation method. The Prefatory of EnvisionTEC Company is the first

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http://dx.doi.org/10.1016/j.jmatprotec.2016.12.016
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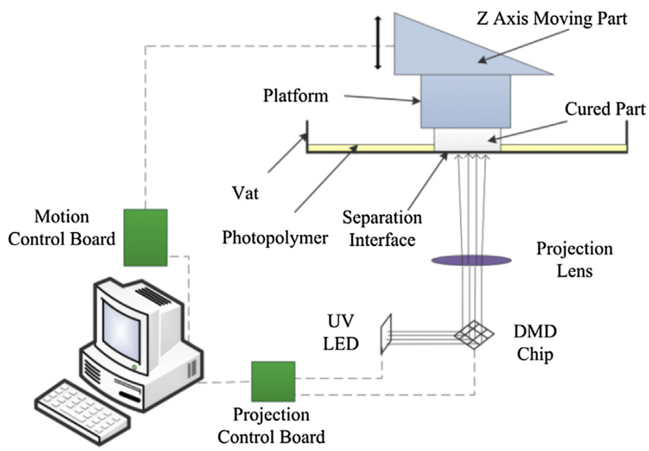

Fig. 1. Schematic of bottom-up MPSL system.

industrial bottom-up MPSL machine using digital light processing (DLP) technology of Texas Instruments, and the company uses tilting mechanism to assist separation process (John, 2007). Pan et al. (2012b) developed a two-channel system wherein the vat surface was half coated with polydimethylsiloxane (PDMS). After curing a layer, the vat moved in x-y plane so that the adhesion was broken by shear force, and this method was also used in B9creator MPSL machine (Joyce, 2012). The Cerafab from Lithoz GmbH (Schwentenwein and Homa, 2015), which was designed for manufacturing high performance ceramics, applied tilting mechanism as one optional process procedure of ceramic green body fabrication (Felzmann et al., 2012).

Inert films such as fluorinated ethylene propylene (FEP), polytetrafluoroethylene (PTFE) and PDMS are used to reduce the separation force. Tumbleston et al. (2015) demonstrated a method which created an oxygen inhibited liquid interface in the exposure area of bottom-up MPSL. This method avoided the generation of separation force for free-radical system resin that has oxygen inhibition and realized fast continuous printing. However, this method still has problems for fabrication parts with large section area and materials of other system or high viscosity materials like ceramic slurry. The inert film method is a common practice of bottom-up MPSL because its high adaptability. However, the inert film cannot avoid separation force completely. The adhesion between film and cured photopolymer forms during each layer fabrication.

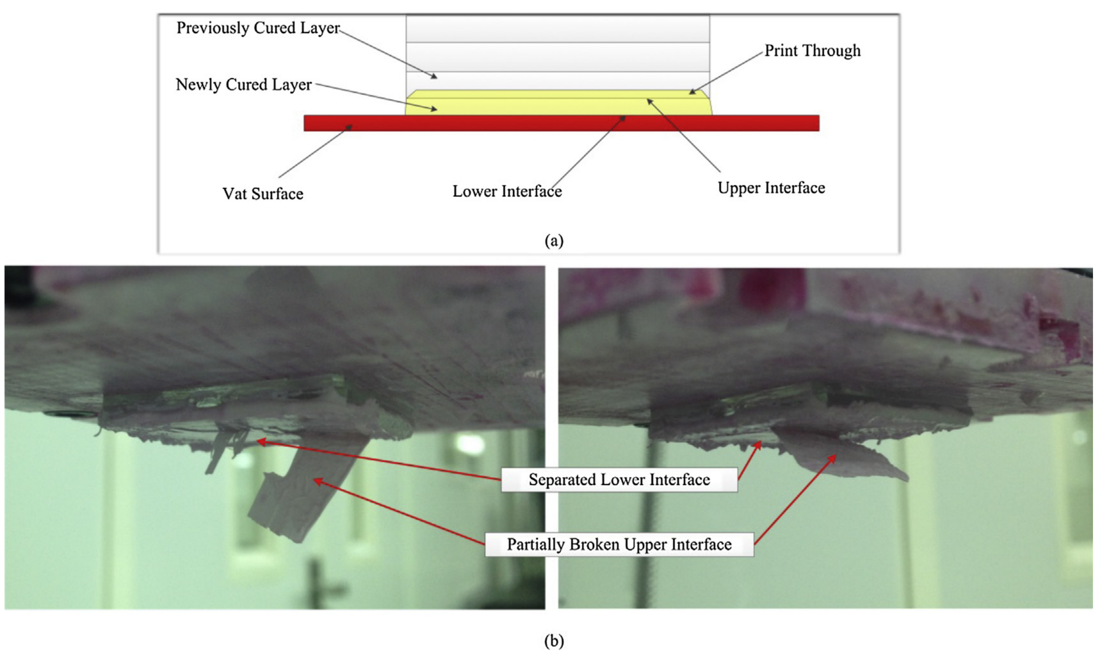

Fig. 2. (a) The formation of the upper and lower interface during each layer fabrication of bottom-up MPSL; (b) failed fabrication case that the adhesion of upper interface is weak.

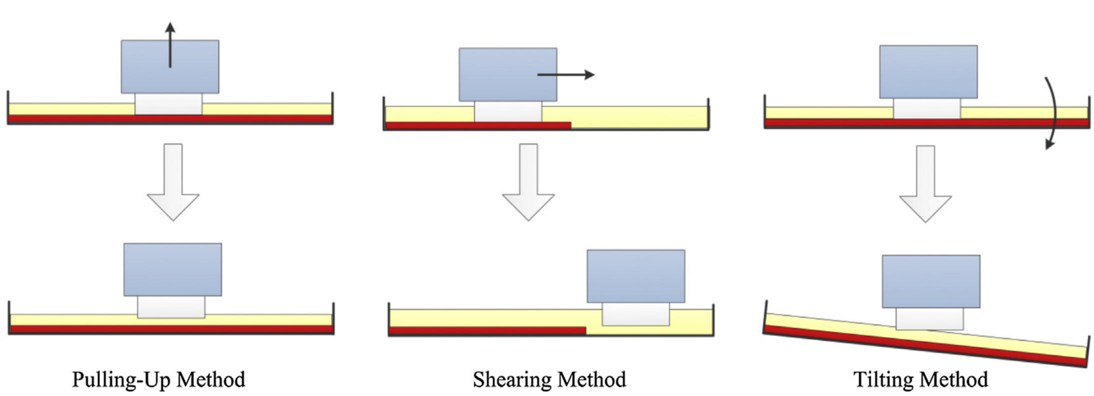

Fig. 3. Three motions of platform for separation used in both industrial and academic area.