International Journal of Latest Trends in Engineering and Technology
Special Issue IC3NS 2018, pp. 009-013
e-ISSN:2278-621X

A REVIEW ON VAT PHOTOPOLYMERISATION TECHNIQUES

Annandita Singh Bhati[1], Pinaki Ghosh[2]

Abstract—Additive manufacturing (AM), also referred as three-dimensional printing or rapid prototyping, has been employed in various areas such as lightweight engineering, architecture, robotics, prosthetics, dentistry and drug delivery. It has emerged as one of the most promising technology for developing the custom manufactured products in the past three decades. AM builds objects layer by layer eliminating the need for moulds or machining by exploiting digital information storage and retrieval via the Internet. The common technique that is used in the three-dimensional printer is the Stereolithography (SLA) process based on photo-curable resin material. These three-dimensional printers offer high dimensional accuracy, quality surface finish, and a variety of material options. This paper presents some recent research on the topic of digital material fabrication using vat photopolymerisation technique.
Keywords— vat photopoymerisation; stereolithography; additive manufacturing; LCD panel; photopolymer resin

1. INTRODUCTION

It has been more than two decades of research, development, and practice, the additive manufacturing industry continues to expand with the introduction of new technologies, techniques, tools, materials, applications, and business models. Meanwhile, a significant growth has been observed in the number of industrial sectors and geographic regions that are embracing the use of AM. It has had a great impact on design and manufacturing, creating new opportunities for custom made products [1].

The significant features of AM are as follows:

reduced waste material
supports high shape complexity
tool-less production
option for personalisation

Layer-based additive manufacturing (AM) is a collection of techniques for manufacturing solid objects from 3D CAD virtual models.

Material extrusion is an additive manufacturing process in which material is melted and selectively extruded through a nozzle. Fused filament fabrication (FFF), fused deposition modelling (FDM), 3D bio plotting, and 3D dispensing can be grouped into this category.

Vat photopolymerization is an additive manufacturing process in which liquid photopolymer resin material in a vat is selectively cured by Ultraviolet (UV) light. Many of the lithography-based AM approaches such as digital light processing (DLP), stereolithography (SLA), LCD-based resin printer and continuous liquid interface production (CLIP) comes under this category.

Powder bed fusion is an additive manufacturing process in which thermal energy (provided, e.g., by a high power laser or an electron beam) selectively fuses regions of a powder bed. Selective laser sintering (from 3D Systems) and laser sintering (from EOS) and electron beam machining (EBM) fall into this category [2].

Stereolithography method is widely used because of the below mentioned reasons:

produces high resolution prints
available in the small size that can fit on the desk
feasible rates
capable of printing intricate designs
relatively quick process

In this review, we will be focusing on the recent advances made in the field of vat photopolymerisation technique for rapid manufacturing.

2. VAT PHOTOPOLYMERISATION TECHNIQUES

2.1 Stereolithography (SLA)

Stereolithography (SLA) is the veteran of 3D printing technologies. The term 'stereolithography' was first devised Charles (Chuck) W. Hull, who later came to be known as "The father of SLA" laid the foundation for this technique and for commercial additive manufacturing as well [2].

In stereolithography, photopolymer resin and ultraviolet (UV) laser are used to build the object layer by layer (Figure 1). At every layer, laser beam draws a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet

[1] College of Engineering & Technology, Mody University of Science & Technology, Lakshmangarh, India
[2] College of Engineering & Technology, Mody University of Science & Technology, Lakshmangarh, India

laser light cures the resin, selectively solidifies the pattern traced on the resins and adhere it to the layer below. After that SLA's elevator platform lowers down by a distance equal to the thickness of single layer, the process is repeated until the object is completed. After the completion of this process object is placed into the chemical bath so as to remove extra resin and consecutively cured in an ultraviolet oven [3].

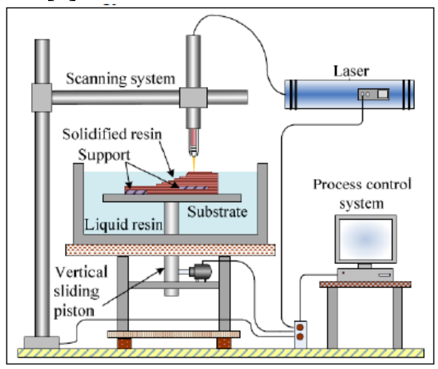

Figure 1. Schematics of stereolithography

2.2 Digital Light Processing (DLP)

Digital light processing (DLP) is very similar to the SLA method except that instead of using a UV laser beam to cure the photoresin, a safelight (light bulb) is used. Each layer (slice) is exposed not point-by-point but rather all-at-once with a selectively masked light source, generally resulting in build time considerably shorter than SLA (Figure 2). The information for each layer of the build part is provided in the form of black and white images. Such binary patterns are generated with the help of digital micromirror device (DMD) chips, a technology also used in overhead projectors [4].

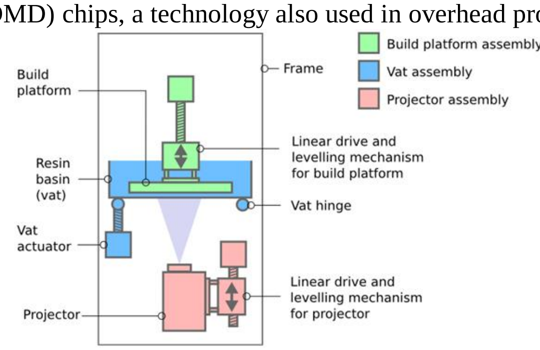

Figure 2. Diagramatic representation of DLP printer

The light sources used in this type of setup have rapidly evolved from classical arc lamps to modern light-emitting diodes (LED) covering a range of wavelength from deep UV to visible. DLP 3D printing is faster in comparison to the traditional stereolithography (SLA) process and can print objects with a higher resolution.

2.3 Continuous liquid interface production (CLIP)

Continuous liquid interface production (CLIP) is a variation of vat photopolymerization AM invented by DeSimone et al. [5], which uses an oxygen permeable, UV-transparent window placed at the bottom of the liquid resin vat to inhibit polymerization at the surface close to the UV source and as a result eliminate the need for tiltable stage which is responsible for recoating step for each layer. Oxygen concentration at the bottom of the liquid resin bath is thus sufficiently high to create a "dead zone" so that radical polymerization cannot take place. The dead zone created above the window retains a liquid interface below the advancing part. Above the dead zone, the curing part is continuously pulled out of the resin bath, thereby creating suction forces that constantly renew reactive liquid resin (Figure 3). Because the resin recoating step is the most time-consuming action of the DLP lithography process, CLIP is significantly faster than traditional DLP, allowing fabrication of objects with feature resolution below 100 micrometers at z-axis growth rates of 30 cm per hour.

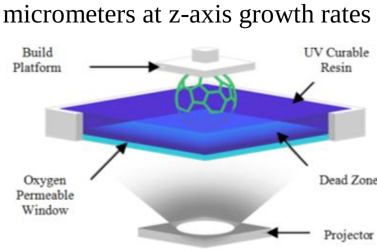

Figure 3. Continuous liquid interface production (CLIP) technique

Although the CLIP device by Carbon, Inc. offers high resolution prints at relatively faster printing speed, the expensive subscription based pricing model leaves it inaccessible to many.

2.4 LCD-Based Three Dimensional Resin Printer

LCD-based three-dimensional resin printer is based on the vat photopolymerization technique for additive manufacturing that use liquid resin for the printing material [6]. Essentially, the printing method in the LCD-based three-dimensional resin printer is similar to the other technologies in the Stereolithography process like DLP and DMD projection which exposes the photoresin using UV light until the material has completely cured, that is liquid resin gets hardened layer by layer leading to the production of three-dimensional solid object. The major difference is only the usage of LCD panel to generate the pattern instead of the DLP projector. Unlike the DLP-based three-dimensional printing which use mercury vapour lamp for producing UV light projections, LCD cannot give off the UV light by itself, a lighting system comprising of LED array is required to cure the liquid material. In order to cure the material, the light must be able to pass through the LCD panel onto the curing area.

Principally, the mechanism of the LCD-based three dimensional systems can be divided into three main mechanisms which are as follows:

Lighting source for curing resin

LCD panel for projecting patterns

Build platform for uplifting the cured object

Lighting System

Since liquid resin is used as the printing material, the lighting system forms an essential part of the system that has responsibility to cure the resin into the solid layers of object. In order to cure every layer of the printed object, the light emitted by the lighting system has to pass through the LCD panel.

LED stands for light emitting diode which is the latest technology in the lighting field. When compared to other kind of light sources or lamps, LED has certain advantages such as small size, low power consumption, and longer lifetime (Figure 4). The selection of single lighting source (or single lamp) or LED array must be done in such a way that it does not generates much heat which can adversely affect the performance of LCD panel as most of the LCD panel have operating temperature below 70ºC [6]. Additionally, to achieve the uniformity of light distribution, the optical system is needed. In case of LED array, the specification of the LED plays a crucial role in determining the circuit connection and the decision of power supply.

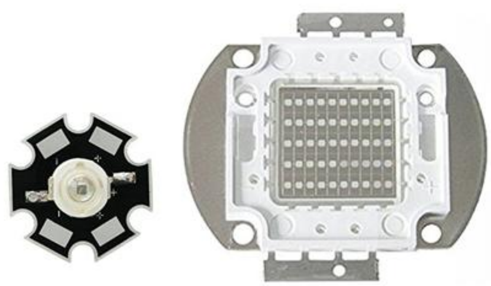

Figure 4. From left to right: Single 3 Watt UV LED which can be used to create LED array, 300 Watt 405 nanometers UV LED chip

In the usage of the optical system including lens, the distance and focal length must be calculated appropriately and placed accurately. Generally, in this method of the lighting source much area or place in the whole system is occupied by the placement of the lens and optical devices.

The placement of every LED in the LED array is done in such a manner that they are placed at the equal distance so as to get the uniform light distribution. Besides, a DC fan is added below the LED array to keep the temperature below 70ºC.

2.5 Liquid Crystal Display Panel

In this three-dimensional printer setup, the LCD panel is the pivotal element of system. It is responsible for generating the layer patterns onto the curing area. These days, the development of the LCD panel technology is increasing resulting in the several kinds of LCD panel types. A Thin film Transistor (TFT) LCD panel makes a great choice because of the advantages it has to offer, such as low power consumption and the easy handling (Figure 5). Another key point in the choosing the type of LCD panel is the pixel density (resolution) which is measured in pixels per inch (PPI). The more the number of pixels in a digital image, the result is closer to the actual picture therefore the precision, size and shape of the printed object is directly affected by this factor.

Figure 5. 6-inch TFT LCD panel with controller board

To be able to generate image patterns onto LCD panel, a LCD controller is needed. The controller converts and transforms data from another imaging device like a computer into a format suitable for communication with LCD panel.

Build Platform

Build platform in the Stereolithography process is the place or area that the printed object attaches with. Once a layer gets cured, the build platform lifts up to release the printed object layer from the resin vat (container). The printing material that is used in this additive manufacturing technique is resin, which is quite expensive, starting from Rs. 8000 per litre. Therefore, it is beneficial to choose the bottom up method instead of top down build approach due to the limited volume of resin it uses to cure objects. To aid the process of lifting up and moving down, the platform is attached to a linear stage (z-axis) that is driven by a DC stepper motor.

Figure 6. NEMA 17 stepper motor

Stepper motor is selected because of the high precision of the movement it offers. It is important because the layer thickness depends on its motion. Since the cured object material gets solidified and becomes hard, it needs sufficient power to release the platform from the resin vat. In other words, an appropriate torque of the motor is needed to be able to drive up the build platform. A NEMA 17 stepper motor can be used to drive the movement of the build platform (Figure 6). It is small in size with the dimensions 42 mm x 42 mm x 39 mm, yet delivers a powerful torque up to 52 N.cm.

2.6 Literature Survey

Over the time, researchers have conducted several investigations to improve the quality of three-dimensional printed objects obtained with the Stereolithography technique by conducting experiments on various components of the three-dimensional printer system. Moreover, continuous efforts are being made to improve the printing speed of the vat photopolymerisation based printers by 1) making suitable changes to the lighting system and optics device placement, 2) studying different resin material composition, 3) analyzing the separation force of cured layer and 4) studying role of oxygen-aided inhibition layer for faster curing rate. Collectively, these factors contribute to the performance of a LCD based three-dimensional resin printer.

The authors of [6] have proposed a new method of the lighting source in the LCD-based three-dimensional resin printer to improve the efficiency of the printing process using LED array instead of single light source. The research shows that the exposure time using LED array as lighting source could be significantly reduced, being around 25-30 seconds for each layer. It means by using LED array as a lighting system in the LCD-based-three dimensional resin printer can increase the efficiency of the printing process around 78% instead of the using conventional light system or single light source. The term efficiency is not only applied to the printing speed, but also the power consumption, wherein the power consumption of the lighting source has been reduced until 74%.

The authors of [7] have presented a two-channel system design for the mask-image projection-based Stereolithography process that also supports the fabrication of heterogeneous objects (which combines two different resins that cure at different rates). In such a setup, a thick coating of PDMS film is applied on the resin vat and linear motions in two axes, which is the movement of frame as well as linear stage that is being used to reduce the separation force of a cured layer and accelerate printing speed (Figure 7).

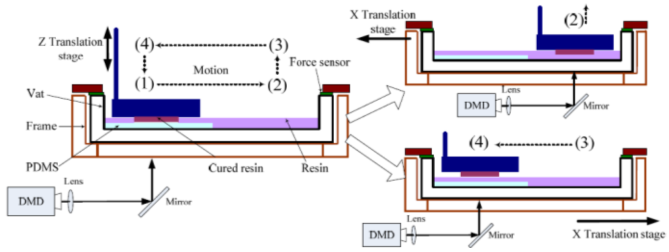

Figure 7. Two-channel system with PDMS

While building a multi-material object, two-stage cleaning strategy has been developed to avoid resin contamination during the process of resin vats. It was also observed that without changing resin vats, the printing speed of the process for a single material is rather fast (~15 second per layer). The research surely proves that by combining multiple resin materials with various concentrations and chemical properties, it is possible to achieve desired characteristics such as multiple mechanical, chemical, biological, electrical and optical properties in a single object and can have numerous applications.
The authors of [8] have conducted an investigation on the separation force in a bottom-up projection based SL process. A visible UV light with bandwidth of 380nm ~ 450nm is used. A DMD chip is used to project binary image patterns. In addition, a conventional layer-by-layer build-up mechanism is applied in this force study. It has been observed that the separation force differs for different printing geometries, and it keeps changing during the printing process even with all the process parameters fixed. Factors that influence separation force include the thickness of initial oxygen-aided inhibition layer, build platform pull-up speed, liquid resin viscosity and printing geometry which could be solid geometry or porous geometry. In case of solid geometries, the printing area to perimeter ratio plays an important role in determining separation forces. The growth rate of separation force is directly proportional to the solid area to perimeter ratio. Even with fixed process input parameters, the separation force still may change dramatically during the printing process, causing the manufacturing process to be unreliable and non-repeatable. This happens mainly because of the variation in oxygen concentration near the constrained surface. When the oxygen supply is insufficient, the thickness of the oxygen inhibition layer near the constrained surface keeps decreasing over the printing process, causing separation forces to increase with the number of layers printed. Investigational results show that a porous air-permeable window could be introduced for supplying oxygen consistently during the manufacturing process, for controlling the increasing trend of separation force.

3. CONCLUSION

At the beginning of the 21st century, additive manufacturing has provided a versatile platform for the development of computer-assisted designs into three-dimensional objects having advanced mechanical and material properties. Focus is increasingly shifting towards the manufacturing of functional products, thereby eliminating the need for post-curing process. In the development of a LCD based three-dimensional resin printer, there are major challenges such as selection of correct lighting source system and LCD panel, overcoming separation forces of cured layer, controlling oxygen-concentration near constrained surfaces, studying chemical nature of photopolymer resin (viscosity, pigmentation and curing rate) and printing complex geometries (porous and solid objects). In this paper, we reviewed different research papers which wherein authors have proposed different techniques to deal with the above mentioned challenges and certainly paves the way for the development of an effective and innovative printer mechanism in future.

4. REFERENCES

[1] Terry Wohlers, “Recent Trends in Additive Manufacturing”, In: Proceedings of AEPR’12, 17th European Forum on Rapid Prototyping and Manufacturing , Paris, France, 12-14 June 2012, pp. 1-3.

[2] Samuel Clark Ligon, Robert Liska, Jürgen Stampfl, Matthias Gurr and Rolf Mülhaupt, “Polymers for 3D Printing and Customized Additive Manufacturing”, Chemical Reviews, vol. 117, no. 15, 2017, pp.10214-10219.

[3] A Selimis and M. Farsari, “Laser-Based 3D Printing and Surface Texturing” in Comprehensive Materials Finishing, vol. 3, Elsevier Inc., September 2016, eBook ISBN: 9780128032503, pp. 111-112.

[4] Ultraviolet (UV) – Overview, http://www.ti.com/dlp-chip/advanced-light-control/ultraviolet/overview.html (accessed Nov 29, 2017)

[5] Joseph M. Desimone et al., “Continuous liquid interface production of 3D object”, Science Express, American Association for the Advancement of Science, vol. 347 no. 6228, March 2015, pp. 1349-1350.

[6] Cho-Pei Jiang and Meizinta Tika, “Development of LCD-based Additive Manufacturing System for Biomedical Application”, In: ICAIR-CACRE '16 Proceedings of the International Conference on Artificial Intelligence and Robotics and the International Conference on Automation Control and Robotics Engineering , Kitakyushu, Japan, article no. 22, ISBN: 978-1-4503-4235-3, 13 – 15 July 2016, pp. 22:1-22:6.

[7] Chi Zhou, Yong Chen, Zhigang Yang and Behrokh Khoshnevis, “Digital material fabrication using mask- image- projection- based stereolithography”, Rapid Prototyping Journal, vol. 19 no. 3, 2013, pp. 153-165.

[8] Yayue Pan, Haiyang He, Jie Xu and Alan Feinerman, “Study of separation force in constrained surface projection stereolithography”, Rapid Prototyping Journal, vol. 23 no. 2, 2017, pp. 353-361.