

Parameter Optimization For Photo Polymerization Of Microstereolithography

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Abstract. This paper presents a research on composition photo absorber (Sudan I) effect based on curing parameter, the Liquid Crystal Display (LCD) projector as energy light source initiated the photo reactive polymer. The polymer based material with composition of 1, 6- Hexanediol dicrylate, Phenylbis(2,4,6-trimethylbenzoyl) phosphine oxide with varied Sudan I concentration was used to build 3D structures. The structure was fabricated with three different photo absorber concentrations 0.002%, 0.003%. and 0.006%. of Sudan I. In this experiment the photoreactive polymer solidification phenomena was evaluated. The experiment result obtained, that exposed time of the varied photo absorber was most significantly affect the surface roughness values and the solidification layer time regardless the layer thickness. This work represents that photo absorber composition solution gave a different characteristics for 3D microstructure fabrication.

Introduction

Free-form fabrication is a very promising technology due to the efficient and simple process for creating microstructures. Projection stereolithography is a three-dimensional fabrication technology that is based on a photo polymerization reaction. The first commercial stereo lithography (SL) machine was released by 3D systems in 1988 [1-2]. In 1993, Ikuta et al. introduced microstereo lithography technology and developed several types of micro-stereo lithography apparatus[3]. Then in 1997, Bertsch et al. developed a micro-stereo lithography apparatus employing a pattern generator in which a Uv laser and dynamic LCD pattern generator were used to generate the cross section of a 3D structure [4-7]. The principle in projection-based stereo lithography process is whereby the pattern of a sliced section is focused on the resin surface at one time and the light source can be generated from a laser or a lamp. The light source of traditional image processing machines like projectors is commonly white light; therefore, it is completely reflected to the focusing time and the thickness of structures built. A number of previous researchers have reported on using some form of light absorption or polymerization inhibition as means for reducing cure depths in MicroSL, resulting in more precise feature detail. The pioneering work of Zissi et al. [8], for example, theoretically derived the cure depth and width according to light absorption, and further showed both theoretically and experimentally that cure width and depth could be reduced using a photo absorber and these effects were shown as a function of the concentration of photo absorber in solution.

This study intends to investigate the photo absorber composition effect on curing temperature, layer thickness and mechanical properties of 3d structure fabricated using a normal LCD projector as energy light source. The surface of fabricated structure was measured and analysed with Surface Roughness Tester. The 3-D structure fabrication are closely related to layer curing characteristic and therefore it is important to gain insight the relationship of photo absorber composition affecting solidification layer time, layer thickness and the mechanical properties.

Experimental Detail

Experimental Set up

Fig.1(a) shows a schematic drawing of the experimental apparatus for the photo reactive polymer solidification experiment consist of a Liquid Crystal Display (LCD) projector ,converging lens, reflecting mirror, resin vat and z axis stage following the first projection stereo lithography developed by Bertsh in 2003. Fig.(b) The 3M LCD projector with light source of 150W UHB 1800 ANSI Lumen was used and this data projectors emit enough UV light to initiated free radical reaction of polymerization. The structure pattern was drawn using Power Point software as the dynamical sliced section layer of the part with a black and white region images, and reflects the patterned light towards the projector tube lens. Red region images was used to calibrate sharp images on the top surface of the solution at Z axis stage, this red light text source will not polymerize the polymer solution.

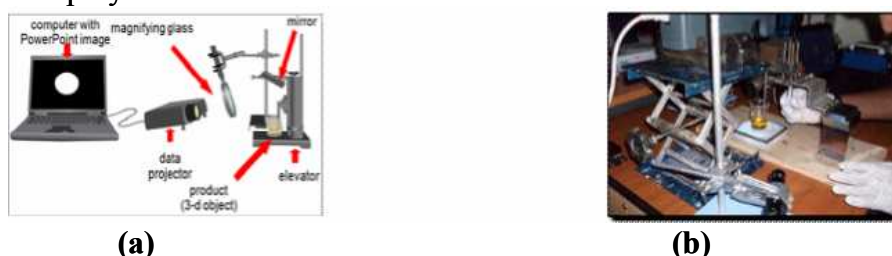


Fig. 1 (a) schematic drawing of the projection stereo lithography system apparatus from Bertsh. (b) lab experiment apparatus system build.

Composition effect on solidification time.

Photopolymer material preparation

The structure material composition was mixed with 98 ml of photoreactive polymers 1,6 - HexanediolDiacylate (HDDA; CAS 13048-33-4, Sigma Aldrich, USA), 2.00 grams of Phnylbis (Irgacure 819; CAS 16288 1-26-7,Sigma Aldrich,USA) as photoinitiator was fixed at a concentration of 2% by weight and Sudan I (Sudan 1; CAS 842-07-9, Sigma Aldrich,USA) was added in the solution with concentration from 0.006 % by weight in HDDA. For this experiment, the concentration of Sudan I was mixed three concentrations 0.002%, 0.003%. and 0.006%.The solution was allowed to mix in a sealed vial on a magnetic bar stir plate thoroughly at least 24 hours to become fully homogenous.

Composition effect on total layer thickness.

Z Stage Distance

In this set of experiments, the customized z axis stage elevator attached with high gauge micrometer was built with a scale range of 0-15mm and a minimum range travel $5\mu\text{m}$. In this experiment the 3D structure was constructed layer by layer consisted of 100 layers. The stage holding the structure was lowered by alternating with black screen and 2D white projection images. The stage then moved deeper into the liquid after solidification of each successive layer, leaving thin layer of liquid above the previously cured layer. The focusing time varied from 5s, 10s and 15s, the z axis stage distance held constant $5\mu\text{m}$ for each layer to polymerize. The 3d structure was constructed using 100 layers for each focusing time interval set-up.

Composition effect on temperature and light intensity.

The distance between light source and stage was set as 3 level; (L1) 19.3cm ,(L2) 18.3cm and (L3)17.3cm. The heavy duty light meter from Extech Inst. was used to measure light intensity values and recorded in Lux scale. The focusing time 5s for each layer until 100s was set up and at different distance, the polymerization temperature was observed as the light energy initiated the polymer solidified from a liquid to a solid state.

Composition effect on Surface Roughness Measurement.

The photo reactive polymer was solidified using varied photo absorber composition and exposed time of Uv light energy absorbed. The solidified surface was measured with surface roughness tester machine (Mitutoyo SJ 400). The sample was placed horizontally on the work bench, and then stylus tip detectors are move down touched the surface of work piece. The indicator level was adjusted to the middle line set as zero datum. The stylus tip indicator move 4mm in distance scratching the material surface parallel to workbench, the surface roughness value was recorded and analyze.

Result and Discussion

Composition effect on solidification layer time.

Fig.2 shown, by reducing Sudan I composition also reduced solidification layer time. The graph indicate that exposure time of different Sudan I composition gave a decrease linear trend solidification layer time. The varied exposed time significantly effect to liquid polymer solidified with sufficient light energy absorbed. The experiment result show, 15s exposed time generated fastest radical crosslink of polymerization reaction and diffuse at the first layer. A quick and intense burst of energy exposed and longer exposed sufficiently provide enough time for the radicals to be generated, and diffuse the polymerization reaction. The solidification layer time can then be used to tune the build time of fabricate structure with a significant composition.

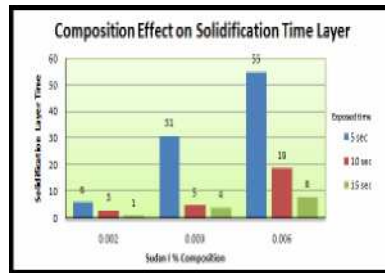


Fig.2 The graph shown a linear pattern of Sudan I effect on solidification time layer

Composition effect on layer thickness.

The amount of photo absorber limits the penetration depth of the light and therefore reduces the cure depth for a given constant photo initiator concentration and light projection. The fabricated layer thickness of structure for each composition gave varied values. As depicted in Fig.3 the graph pattern shown the layer thickness increased as the photo absorber composition reduced. The layer thickness for 0.002g composition between 5s and 10s was 0.00 1mm slightly increased. The 0.003g Sudan I composition with 10s exposed time; experiment result measured total layer thickness was dissimilar cause of the distorted structure formed due to rapid polymerization or non-uniform light. The top layer was highly crosslink, causes the insufficient time for the below layer to diffuse and crosslink reaction.

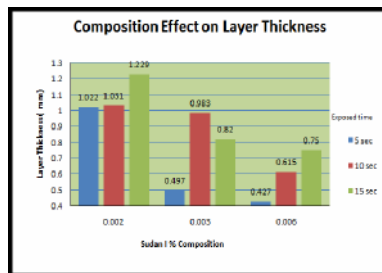


Fig.3 The Composition effect on layer thickness with different exposed time.

Composition effect on temperature and light intensity.

The materials expose to Uv light solidified from a liquid to a solid, in which the energy from light source initiated the crosslinking of molecules and dotted line indicate the liquid was started to solidify known as gel point. Due to radical's reaction polymerization the heat was released and the

temperature measured for each distance. In Fig.4 the graph plotted, the composition of Sudan I depicted different gel point time occurred for each Sudan I composition; 0.002g (28s), 0.003g (40s) and 0.006g (52s). The gel point temperature ranging from 20°C to 25°C for all sample composition. The light intensity observed not much effect polymerization process, this may due to the slim different values used. Sudan I as photo absorber control the light penetration and layer thickness, the result shown Sudan I composition not significantly effect to temperature however, the exposed time was increased due to percentage of light penetration into the resin to initiate the polymer resin.

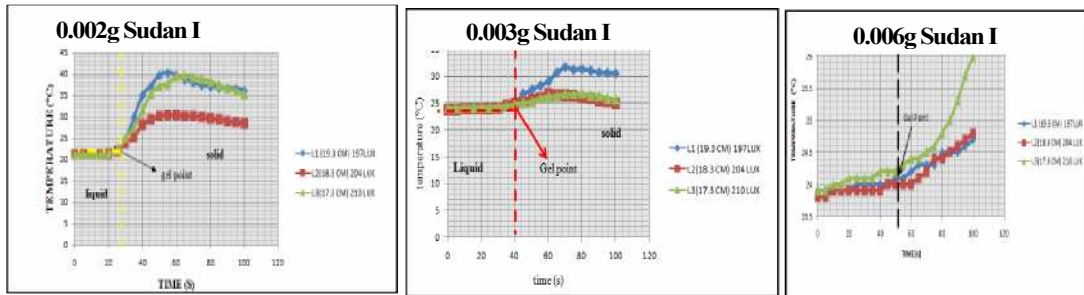


Fig. 4 Three different of Sudan I composition effect on temperature at gel point.

Composition effect on Surface Roughness Measurement.

The graph was plotted in Fig.5 was compared between Sudan I composition and exposed time. The exposed time allow the light energy absorbed initiate the radical’s reaction polymerization from liquid to solid structure. The Fig.5 graphs shown the exposed time increased as the surface roughness value decreased. The lower surface roughness values indicate a smooth and better quality surface formed. As compared to the three compositions mixed, exposed time 15s was sufficient time to photo reactive polymerized. The lowest solidification layer time using 0.002g photo absorber composition also gave the lowest surface roughness value 0.50 μm. Although the roughness value was low, the thicker layer thickness was formed due to crosslink reaction of polymerization.

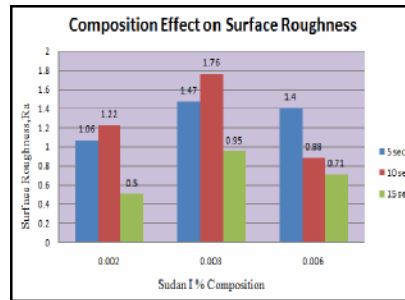


Fig.5 The surface roughness with different composition and time interval.

As table 1 shown that the square structure fabricated by experiment conducted to the surface roughness values depending on the percentage composition of the Sudan I and exposed time used. Each structure provides the physical appearance of different quality. From research conducted, as in Fig. 6 shows are some examples of various forms 3d structure which can be made in the size of micro level.

Table 1. Sample structure fabricated with different Sudan I composition and exposed time.

Exposed time (sec)	Sudan I Composition (gram)		
	0.002	0.003	0.006
5			
10			
15			



Fig.6 Sample of 3d structured fabrication in the size of micro level

Summary

The 3D structure was successfully fabricated by using LCD projector as source light energy. The photo absorber was effectively used to control Uv penetration for fabrication 3D microstructures in micro Stereolithography. However, different concentrations of the Sudan I and exposure time was shown to be significantly affect for successful fabrication. The 0.002g Sudan I shown the fastest solidification time and the lowest surface roughness value 0.50 μm used 15s interval exposed time. A Different mechanical properties can be achieved by varying the Sudan I composition and exposed time regardless the layer thickness. These results provide a clear basis parameter optimizerization for polymerization of these systems by controlling not only the photo absorber but exposed time as well. The results obtained from this experiment is still need to be expanded by some other study to achieve the optimum information with regards to the contribution of Uv light in different methods for fabricating 3d structure with SLA resin, future studies will explore with inkjet printing technology as possibility for fabricating 3d structure.

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