THE RELATIONSHIP OF PROCESS CHARACTERISTICS OF STEREOLITHOGRAPHY TO PROTOTYPE DIMENSIONS

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I. INTRODUCTION

A characteristic of the modern day world is a continuous need for ever changing designs of high quality products. This characteristic, along with lower cost of computing, has led to the development of novel methods for reducing the cycle time of product development in order for companies to garner a competitive edge. Desk top manufacturing or rapid prototyping is one such field of technology which enables companies to rapidly produce a three dimension model from a computer data base. An overview of this rapidly expanding field is given in [5,9]. Among the more common of these modern processes are stereolithography (SLI) [2,3], the DTM process [6], powder metallurgy prototyping [4], and metal spraying of stereolithography parts [8].

An overview of the stereolithography process has been presented in [3]. In addition, certain process characteristics and a general projection of tolerance values of finished part dimensions have been identified in [1,7]. However, the relationship between the two has not been established in the available literature. This research focuses on developing a more quantitative understanding of important process parameters and dimensions of finished parts that are produced using stereolithography.

II. EXPERIMENTAL DESIGN

A Taguchi system [10] of experimental design is used in this research to establish the relationship between process characteristics and product dimensions. This experimental system is designed around the premise that the objectives of an experiment are to obtain information on the contribution that experimental parameters have on the yield or response of the experiment such as product dimensions. The experiments are designed such that the parameters which have mutually interaction are identified. This enables the contribution of individual parameters on the response to be more clearly correlated. In a conventional system of experimentation where one parameter is kept constant and others varied sequentially, interaction between parameters cannot be precisely identified. Furthermore, variability in the responses cannot be attributed to the contributing parameters, whereas in a Taguchi system, variability of responses may be more accurately related to contributing parameters.

Since stereolithography is a new process, there is little information available about process characteristics. Hence the approach used is to identify the experimental parameters, based on preliminary experiments and available expertise. This has led to seven major operating parameters of the stereolithography process being identified for investigation. These parameters include support design, layer thickness, crosshatch spacing, wait time of leveling, cure depth of boundary and cross hatch, cure depth of skin fills, and Post Cure Apparatus [PCA] exposure time. The levels of each parameter are shown in Table 1. With the primary objective of identifying the contribution of main factors and existence of interaction, the Taguchi system makes use of an L_iN^R orthogonal array, where L_i refers to "i" experimental runs, "N" corresponds to the number of levels of each parameter and "R" refers to the number of parameters in the experiment. For example, Table 2 depicts the main experiment, which is a $L_8 2^7$ orthogonal array that uses eight experimental runs for investigating the contribution of seven parameters, each of which has two levels [11]. The corresponding responses Y_i (for example, product length) are obtained for each run.

In order to corroborate the orthogonality of the various parameters in each experimental run, the parameter magnitudes at levels 1 and 2 in Table 2 are replaced by dummy integers -1 and +1 respectively [11]. The following relationship must then be satisfied in the new array that is created from Table 2:

$$\sum_{i=1}^{8} (A_i \ B_i) = 0 \tag{1}$$

where A and B represent any two parameters of the chosen seven, in any order, and i represents the experimental runs 1 to 8. Once a condition of orthogonality is established, the average effect of a parameter at level j on the response, E_j, (j=1,2), is obtained as:

$$E_j = \sum (Y_j) / 4 \tag{2}$$

where Y_j are responses obtained for each experimental run where the particular parameter is set at level j. In order to obtained the effect of changing a parameter level from level 1 to level 2, the measure D for any parameter is identified where:

$$D = E_2 - E_1 \tag{3}$$

Since the main experiment in this research uses a $L_8 2^7$ orthogonal array, there is an inherent two parameter confounding built in the design. This means that the contribution of main parameters and two factor interactions cannot be segregated. Hence it is necessary to conduct a set of experiment known as foldover experiments in order to segregate main effects and interaction effects that various parameters have on the response. These foldover experiments however, form the next phase of this research.

III. EXPERIMENTAL PROCEDURE

The main equipment used in this research is a Stereolithography Machine (SLA-250). The first step is to create a CAD solid model for the part that is to be made (Fig. 1a). This CAD model is sliced by slice software into very thin cross sections which are then loaded onto a control computer. A Helium Cadmium (HeCd) laser is then focused on the surface of liquid photopolymer (CIBA TOOL - XB5081) and moved by a computer-controlled optical scanning system in a path that replicates a particular cross section (Fig. 1b). Upon contact the laser polymerizes the liquid photopolymer into a solid. A vertical elevator system lowers the newly formed layer, while a recoating and leveling system is used to form a layer of liquid photopolymer over the previous cross section. Successive cross sections, each one of which is laser cured into the one below, are built on top of each other in order to form the part. The entire part is thus created starting from the bottommost cross section. After the last layer is created, the part is removed from the SLA, cleaned, and flooded with high intensity ultraviolet light in the Post Cure Apparatus to complete the polymerization process. The part dimensions are then obtained by using a Mitutoyo Dial indicator on a surface plate. The probe has a tip diameter of 3 mm. Resolution of this indicator is 1 μm and precision is less than 1 μm. Calibration was performed using standard gage blocks.

IV. RESULTS AND DISCUSSION

At this stage of research, the experiment was conducted by using a $L_8 2^7$ orthogonal array which has an inherent two parameter confounding built in the design. It is not possible to isolate the contribution of each parameter as the foldover experiments are in the process of being completed. Hence only the maximum breadth and width deviations, and geometric shape errors are reported. Figure 1c depicts the points where measurements are made. Table 3 and Table 4 depict the dimensional and geometric deviations that are obtained. The maximum dimensional deviation is 0.15 mm and the maxmium geometric deviation is 0.28 mm. It is anticipated that the foldover experiment will enable a more accurate assessment to be made of the stereolithography process. This is because the contribution from experimental parameters and their respective interactions may be seperately identified. At present the results obtained serve as an overall measure of the process capability of stereolithography process.

VI. REFERENCES

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Table 1
Experimental parameters with their corresponding levels

S. NO.	PARAMETERS	LEVEL-1	LEVEL-2
1	SUPPORT DESIGN (S)	STANDARD	CUSTOM
2	LAYTER THICKNESS (LT)	0.005" (.127 mm)	0.01" (.254 mm)
3	CROSSHATCH SPACING (C)	0.05" (1.27 mm)	0.025" (.635 mm)
4	WAIT TIME OF LEVELING (WT)	30 SECONDS	60 SECONDS
5	CURE DEPTH BOUNDARY AND CROSSHATCH	0.001" (.025 mm)	0.009" (.228 mm)
6	CURE DEPTH OF SKIN FILLS (CS)	0.008" (.203 mm)	0.016" (.406 mm)
7	PCA EXPOSURE TIME (PCA)	120 SECONDS	30 SECONDS

Table 2
Experimental parameters used and their corresponding levels for main experiment

Runs	Experimental Parameters Levels						
STRN	S	LT	C	WT	CB	CS	PCA
1	1	1	1	2	2	2	1
2	1	1	2	2	1	1	2
3	1	2	1	1	2	1	2
4	1	2	2	1	1	2	1
5	2	1	1	1	1	2	2
6	2	1	2	1	2	1	1
7	2	2	1	2	1	1	1
8	2	2	2	2	2	2	2

Table 3
Dimensional deviations of width and breadth using reference 1 and reference 2 as resting surfaces for measurement

Width (nominal=12.7mm)	Breadth (nominal=25.4mm)
At Axis AC = -0.10 mm	At Axis EG = -0.07 mm
At Axis BD = -0.14 mm	At Axis FH = -0.15 mm

Table 4
Maxmium geometric deviations using reference 1 as the resting surface for measurement

Side	Maximum Deviation	Location
Reference 2	0.23 mm	Middle
Side 1	-0.28 mm	Bottom
Side 2	-0.28 mm	Bottom

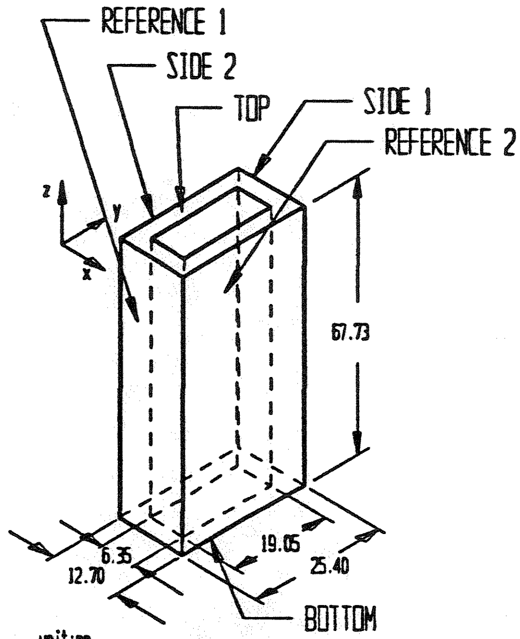

Figure 1a

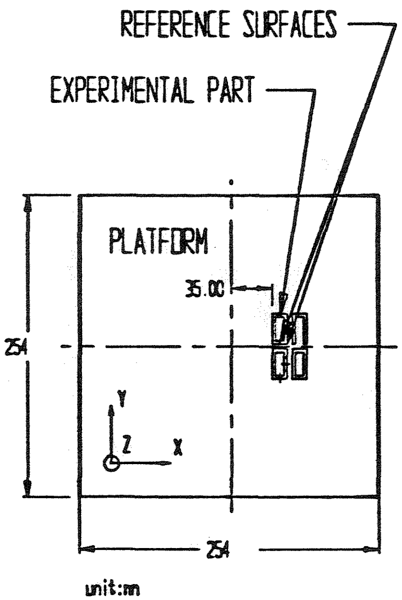

Figure 1b

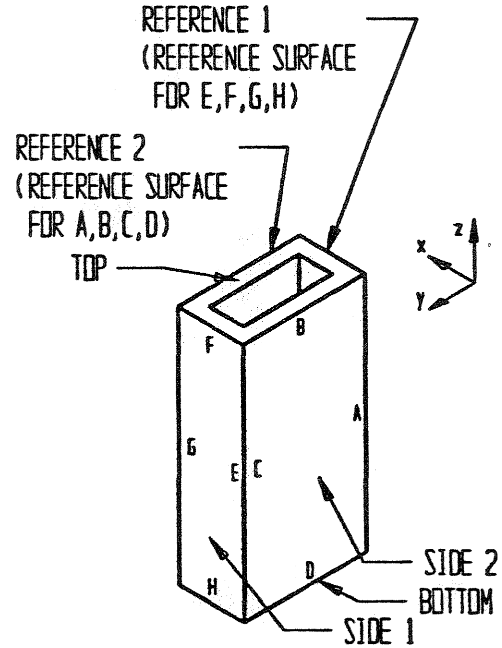

Figure 1c

Fig. 1a Detailed drawing of part that is under investigation.

Fig. 1b Plan view of 4 parts as they are created in the Stereolithography machine.

Fig. 1c Drawing of part showing points of measurement A,B etc. used to obtain dimensional deviations, for example, AC, BD etc. from reference. surfaces.