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Effect of Temperature Variations on Dimensional Stability of Bench Mark Structure Fabricated by Scan Based Microstereolithograhy Process

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***Abstract*- The advent of new Additive Manufacturing (AM) systems has made the use of AM technology to expand its domain into many difficult to manufacture sectors. However, with such expansion, there always exists a need for better understanding of the limitations of these systems. The work in the paper shows an attempt being made to demonstrate the effect of varied temperature on dimensional stability of the Bench Mark (BM) structure fabricated by Scan based Microstereolithography process (SµSL). The BM includes multiple geometric features used to study the intensity of temperature effect with change in size and shape of the structure. The SµSL system will be evaluated for dimensional and geometrical accuracy for change in room temperature.**

Keywords- Scan based Microstereolithography, Bench Mark, Temperature effect.

1. INTRODUCTION

There are as many products as there are kinds of applications. Each new application gives rise to a new dimension in technology development. Over the past few decades, a lot of changes in the technology particularly in the areas of computer integrated design and development process have been introduced into the manufacturing sector. Various computer aided technologies have been used in development of products hard to manufacture the conventional way. To overcome the limitations of conventional techniques of manufacturing, advanced technologies have been developed for fabrication of complex structures. These techniques have been integrated into a multi disciplinary new technology known as additive manufacturing process. One such additive manufacturing technology is Scan Based Microstereolithography (SµSL). Today, many researchers are studying 3D fabrication in smaller sizes and more complex shapes, as mechanical, chemical, and photochemical fabrication technologies have been advanced [1]. Rapid Prototyping (RP) technology has been widely used in the fabrication of such complex sized and shaped structures [2]. Stereolithography is one such RP technique involving resins containing certain chemical properties that are used for photopolymerization. All photocurable resins can be classified under three types; epoxy, acrylate, or vinyl-ether, and all the three types contain fillers and other chemicals to give specified chemical and physical properties [3]. For fabricating micro polymer structures, Microstereolithography is considered to be a promising technology in additive manufacturing domain [4]. Use of such technology in various fields of applications has made researchers to diversify their study from building conventional polymer structures to complex biomedical structures [5].

Dimensional accuracy is a very important factor for a product developed by any manufacturing process and Bench Marking is one of the ways to standardize the process parameters by measurements. In SµSL process, dimensional accuracy is a major issue due to shrinkage after photopolymerization, variation in ambient temperature and various other forms of internal and external constraints. Hence, it is highly difficult to predict the final dimensions of the part after being irradiated to the UV light.

Various studies have been carried out relating to the design of benchmarking parts for AM processes. Kruth [6] initiated the BM studies for AM process by implementing many geometries of different cross section in one single design. The motivation behind such a design was to test the process for repeatability. Later various researchers designed and developed different BM structures for standardizing the AM process. Lart (year) Juster and Childs [7 and 8] used square shaped BM to asses accuracy of various AM process. Though Kruth [6] used U shaped BM, the squares and cylinders with positive and negative features were generally used by all researchers. Many researchers [7and 9] have studied designed BM exclusively for linear measurement with no much important given to the curves. Similarly various researchers introduced many different concepts of BM in order to study the accuracy and tolerances achievable in the AM process. Hence, the current study focuses on development of a simple BM design that can used to evaluate the effect of changing temperature on the overall efficiency of the system being used.

2. DESIGN AND DEVELOPMENT OF BENCH MARK (BM) STRUCTURE.

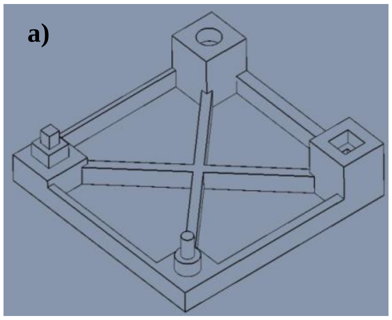
As discussed in the previous section, several researchers have developed various BM in macro scale. However, these BM were never adopted for micro regime. BM developed by Zabit (2012) in association with MEC lab (University of Delaware) was found to be quite suitable for the accuracy measurements of different size and shape in micro regime for the current study.

2.1 Bench Mark design

The BM selected from the extensive literature survey proves the capability to measure all the geometrical features need to be investigated. Micro features such as holes, flat surfaces, cylinders and straight lines could be evaluated. In here three variants of BM were considered:

a. Linear b. Position c. Geometric

The design of BM was made with a size of 10mm X 10mm X 2mm (Fig1 b). To check and compare the accuracy with change in linear dimensions four cube bosses of height 2mm with different cross sections were made based on the design. Out of four cubes two were designed for positive features and the other two for negative (fig1 a). The cubes were designed so in order to investigate the ability of the system in fabrication of negative and positive features. The other features of the BM were also made use of to assess the surface properties of the structure. Also the four cubes were used to find the error in the distances. In order to put the measurement in a proper scale the features of the BM were classified as shown in table 1.



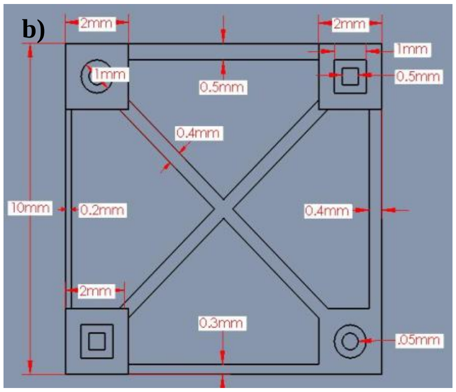


Fig 1: (a) CAD model of the Bench Mark design (b) Dimensions of CAD model

Table 1. Classification of Benchmark features

Feature	Purpose
Cube , square hole	Squareness, linear accuracy and repeatability
Cylindrical Hole	Roundness, accuracy and repeatability of radius (internal)
Solid Cylinder	Roundness, , accuracy and repeatability of radius (external)

3. MEASUREMENTS

To assure an error less measurement for all linear, position and angular, high resolution Confocal Microscope was made use of (fig 2a).The specimens were carefully handled and inspected visually for a defect less structure.

- Linear Measurement: accurate measurement of distances in xy direction for length measurements at different points was made for structures fabricated at three different temperature conditions.
- Circularity measurement: eight points at an angle of 45° from the reference centre were considered for measurement. At each point the radius from the reference centre was taken into account and an accurate measurement was done for all the four circles of each sample.

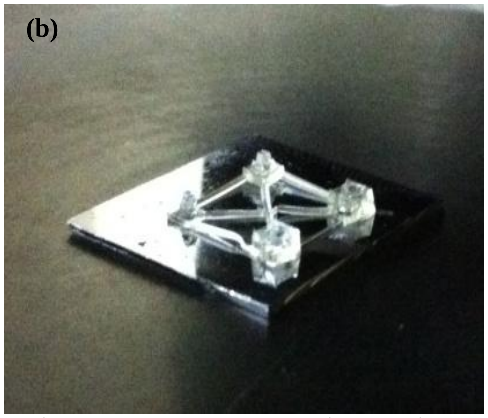
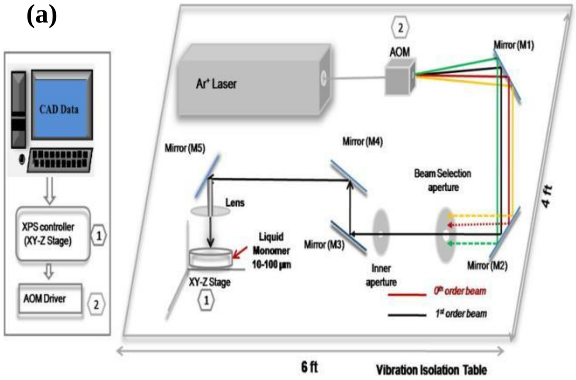


Fig 2: a) Confocal Microscope b) Bench mark fabricated for measurement

4. LAYER BY LAYER FABRICATION OF TEST SPECIMENS FOR CHARACTERIZATION

4.1 Working principle of Experimental setup

The schematic and photograph of the SμSL setup is as shown in fig1. An Argon Ion UV laser of 364nm wavelength was used as the light source and a UV coherent lens to focus the beam on to the resin surface with a Depth of Focus (DOF) or focal length of 50.3mm was used. The other parts of the system comprised of; an Acoustic Optic Modulator (AOM) used to achieve highly efficient diffracted (first order) beam for effective utilization of UV laser power. Set of optical mirrors and an optical Iris diaphragm (1.5mm–11mm aperture range, 10 leaves, Newport USA) was made use of to guide the beam towards the resin surface with highest possible power and lowest spot size of the beam. An X-Y-Z linear translation stage of 20nm meter resolution, connected to a motion controller drive (Model-XPS, Newport). This linear stage moves the substrate in three orthogonal directions within the photopolymer container irradiated to a fixed UV beam for achieving the programmed structure



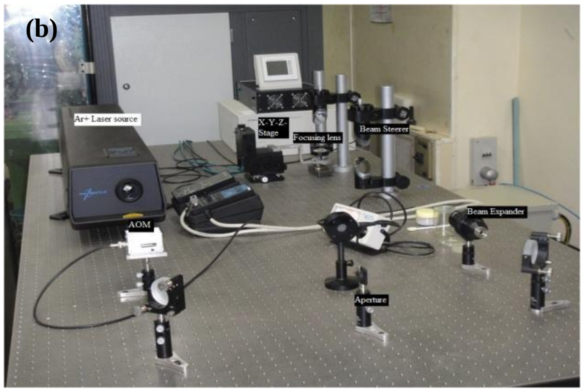


Fig 3: Experimental set up Scan based Microstereolithography a) Schematic representation b) Actual setup

4.2 Preparation of photopolymer for UV curing.

1,6-Hexanediol diacrylate (1,6-HDDA) as monomer and Benzoin Ethyl Ether (BEE) as photo initiator obtained from Sigma Aldrich (USA) was used as procured in precursor preparation. The monomer PI blend of different concentrations was used to investigate the effect of UV laser on the final structure for fixed process parameters. In order to make the photopolymer mixture; the BEE was mixed in fixed proportions to the monomer. In the typical procedure followed for the preparation of photo curable solution, 1, 6-HDDA was mixed with BEE with a fixed volumetric relation. The PI monomer solution was then stirred using a magnetic stirrer at room temperature in a dark room environment for duration of 4 hours.

5. FABRICATION AND TESTING

The design and initial code generation of structures were made using commercial CAD software (UG NX5). The codes were then post processed and made LABVIEW 8.5.1 software compatible. The controlling stage and the AOM are interfaced with LABVIEW 8.5.1 for path generation using pre processed codes. Laser fabrication parameters such as power, and laser spot diameter were optimized on initial solidification trials [5, 6]. By keeping the laser beam spot fixed, the silicon substrate placed on the substrate holder fastened to the linear translational stage is dipped into the vat containing liquid polymer and is subjected to predefine scanning to obtain designed structure.

Experiments were conducted using the SMSL setup. Chemical and parameters related to the physics of the system were optimized to the requirements. After carrying tests on various geometry of different samples, a 3D benchmark was fabricated similar to the one developed by Zabit (2012). The fabrication was done for 3 different temperatures; 22, 25 and 29°C. The 3D benchmark was investigated for linear, form and position dimensions. A laser stability test was also assessed for the beam at two different temperatures using a camera based beam analyzer (LBA-USB, Spiricon). In here, the study was made to gauge the beam profile characteristics and the effect of the same is used to study the system stability at different temperatures.

6. RESULTS AND DISCUSSION

6.1 Linear Dimensions Error

Fig 4 shows the effect of increase in temperature on linear dimensional accuracy. For all the tests the greater the temperature, and the greater the length of the sample, the greater the error. For a lower temperature of 22°C linear dimensions the mean error along X and Y directions of scan were below 15µm, for 25°C the mean error along X direction was found to be 14 µm and along Y to be 22 µm. However, with further increase in temperature to 29 °C the mean error increased to 40 µm in Y direction and around 20 µm in the X direction. For other class of linear dimensions the behavior of the mean error was found to be similar but with a lesser value. Fig. 4 presents the data of mean error in linear dimension in terms of increased temperature, and it is immediately obvious that increase in temperature increased the mean error due to the thermal polymerization and changed chemical behavior of acrylate resin leading to the reduction in the degree of UV polymerization and cross-linking density of the thermoset resin when light absorber is introduced into the compound.

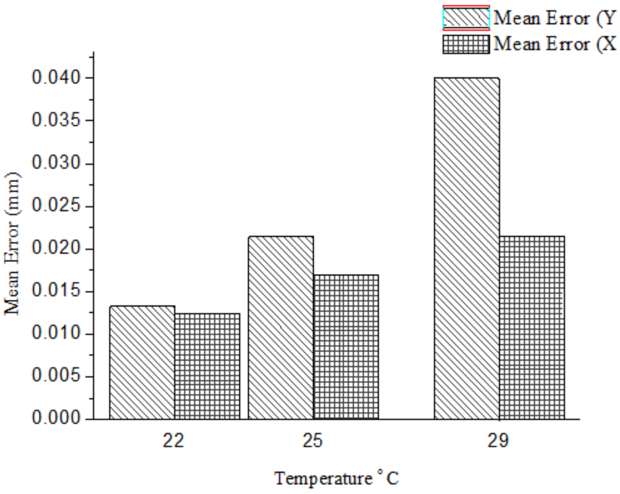


Fig 4: Mean error for different linear group dimension at different temperatures

6.2 Circularity and Position Error

The results for circularity and position measurement mean errors are shown in fig5 and 6. The mean circularity error for temperatures 22, 25 and 29°C were measured for positive and negative features of the circle. When measured for the negative feature (hole) the variance in actual size was found to be more than 15% of the design size for both medium and small size holes. However, the error was found to be much less for positive feature (cylinder) and at a temperature of 22° C the error was well below acceptable limits (ISO 8015). For position error similar results were derived with temperature of 22° C being an ideal condition for working with this system.

Fig 5 and Fig 6 shows error measured for micro cylinders and holes.

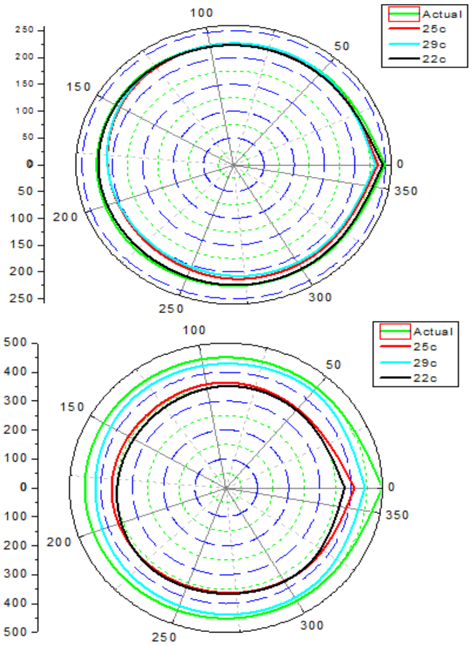


Fig5: Polar plot showing circularity error for a) hole Ø500µm b) Ø 1000 µm

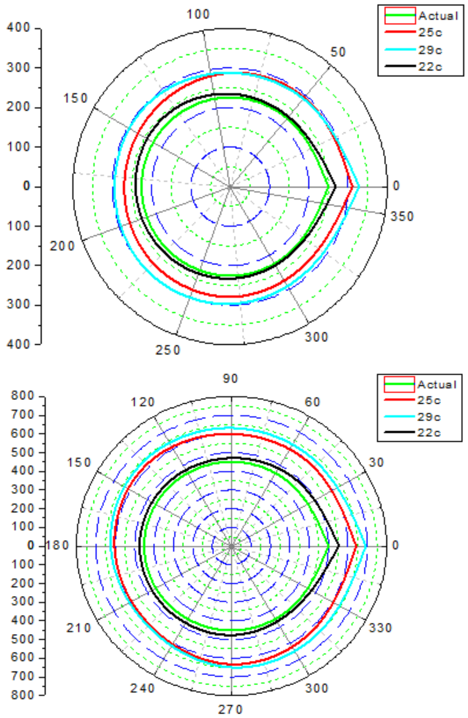


Fig 6: Polar plot showing circularity error for a) Ø250 µm b) Ø500 µm

6.3 Laser beam profile study

In order to check the reason for laser system instability, laser beam spot was characterized for a laser power value of 9mW.

Energy values were input to the beam analyzer after measuring using an energy meter with all other inputs to the device being characterized accordingly. Fig 7 shows the resultant Gaussian beam profile measured for temperature at 22^{o}c (controlled temperature) and 28^{o}c (normal room temperature). From the figure it is evident that with change in temperature, the beam profile changes drastically making the system unstable fabricating components with no dimensional and geometrical accuracy.

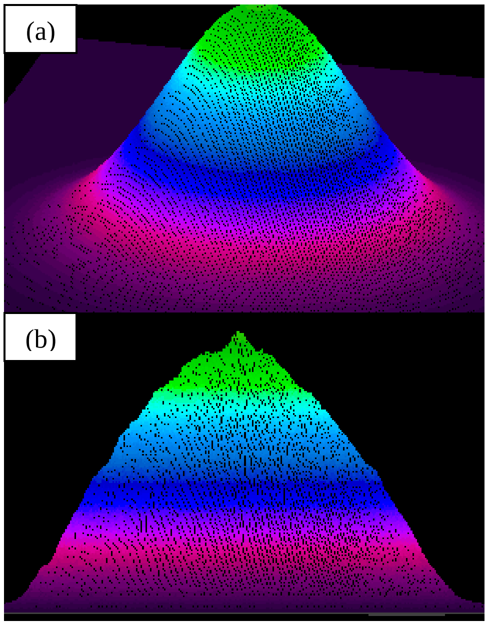


Fig 7: Beam profile test for temperature a) 22^{o}c b) 28^{o}c

7. CONCLUSION

The authors have investigated the effect of temperature on part accuracy in SμSL. Fine tuned UV curable polymer blend was used in the process at different temperatures to study part accuracy in terms of linear dimensions, form, and position. All solidification processes in this study were conducted using an inhouse built Scan based microstereolithography system. Results show that change in temperature has significant effect on dimensional accuracy. For linear dimensions the error increased with length of part and with increased temperature. At a temperature of 22^{o}C the process shows no much significant effect on roundness with positive feature, but nothing much is in acceptable limits along the negative feature and position error at any temperature. The process remains stable and works efficiently at temperature not more than 22^{o}c. this is quite evident from the beam profile test carried out at two different temperatures

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