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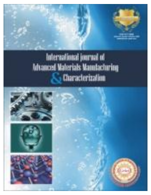

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Geometrical Accuracy of Parts Produced by Rapid Prototyping Technique (Sls)

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The present work has been carried out to identify various geometrical characteristics of the parts produced by Selective Laser Sintering (SLS) technique using different process parameters like part built orientation and sintering temperature. A geometrical bench mark part with different shapes and features is produced by SLS process with polyamide powder material. The bench mark part is inspected using CMM to know the geometric errors like roundness, perpendicularity, parallelism, concentricity etc. Effect of build orientation and sintering temperature on various errors has been studied and reasons are analyzed. Suitable process parameters are suggested to produce the parts with better geometrical accuracy and these are very much useful in industrial applications.

Introduction

In the present day globalization due to the pressure of the international competition, there will be a strong driving force in industry to compete effectively by reducing manufacturing lead times and costs while assuring high quality products and services. Quick response to business opportunity has been considered as one of the important factors to ensure company competitiveness. Rapid prototyping (RP) has emerged as a key enabling technology with its ability to shorten product development and manufacturing lead time. Selective Laser Sintering (SLS) is one of the RP technique used to produce the required objects using plastics or metallic powders as the materials. The products produced by SLS process can be used for various applications like medical implants, jet engine parts, turbine blades etc. In spite of the above mentioned advantages there have been some limitations related to the quality of parts produced by SLS process like geometrical accuracy, surface finish etc.

Tang et al [1] studied the accuracy issues of a rapid prototyping parts produced by direct laser sintering process and they have classified the errors into different groups like errors caused by laser scanning system, material shrinkage, laser beam spot size and errors caused by slicing software etc. Wong et al [2] designed a benchmark part with typical geometrical features as per ISO standards. An experimental study has been conducted to demonstrate the use of the benchmark part for the performance evaluation of RP processes and machines. The benchmark parts were first fabricated with the default machine parameters and settings. The four well-known RP processes SLA, SLS, FDM & LOM have been used in this experimental study. For comparison of various RP processes accuracy of the objects are measured by using CMM machine. Pandey et al [3] performed experimental investigations to analyze the effect of process parameters on the accuracy of the parts produced by selective laser sintered (SLS) process. The effect of process parameters namely build orientation, laser power, scan speed, cylinder diameter and build chamber temperature has been studied on the geometric accuracy of the parts produced like cylindricity and flatness.

In the present work experiments has been carried out to identify various geometrical errors of the parts produced by SLS technique using different process parameters like part built orientation and sintering temperature. A bench mark part with key features is produced by SLS process and it is inspected using CMM to know the geometric errors like roundness, perpendicularity, parallelism, concentricity etc. Effect of process parameters like build orientation and sintering temperature on the geometric errors has been studied and reasons are analyzed. Suitable process parameters are suggested to produce the parts

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on SLS machine with better geometrical accuracy which is very much useful in practical applications.

Methodology

A CAD model created in solid modelling software (Solid works) is first tessellated and sliced into layers of 0.1mm thickness. This information is used to sinter the selected areas of each layer while producing physical parts. In this study, SLS uses fine polyamide powder which is spread uniformly by a re-coater on the machine bed and scanned selectively by a laser and the powder particles are joined together with the heat of the laser. Before the laser scans, entire machine bed is heated to a temperature below the melting point of the material by infra red heaters to minimize thermal distortion and to facilitate fusion to the previous layer. Laser power is adjusted to bring the selected powder areas to a temperature just sufficient for the powder particles to get sintered. After this, the part bed moves down by one layer thickness (0.1mm) to facilitate new powder layer to be spread by a re-coater. The sintered material forms the part while the un-sintered powder remains in its place and acts as a support for the subsequent layers and may be cleaned away and recycled for next object to produce once the build is complete. The schematic diagram of the SLS machine used in the experimentation is shown in Fig.1.

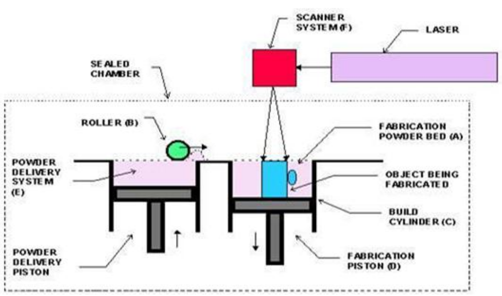

Fig.1 Schematic diagram of Selective laser sintering process

Selection of process parameters and specimen geometry

In order to analyze the effect of build orientation and sintering temperature on various geometrical errors, specimens of benchmark part have been chosen for experimentation. Benchmarking refers to the comparison of performance of different similar systems (organisations, machines, processes etc) with each other to establish a standard of performance. A benchmark as defined by the Webster's Dictionary is "a standard or point of reference in measuring or judging quality, value, etc". Benchmarking is used not only to compare the strength/weakness of the parts but also to measure and compare accuracy, surface finish, repeatability and resolution of the geometrical features of the parts produced. Fig.2 shows the design of a benchmark part in Solid works for experimental study. The process parameters and their levels used in the present study are summarized in Table1.

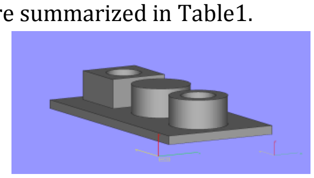

Fig.2 Design of benchmark part for SLS process

Table 4 Experimental plan

Sl. No.	Parameters	
	Orientation(deg)	Temperature (°c)
1	0	171
2	0	172
3	0	173
4	45	171
5	45	172
6	45	173
7	90	171
8	90	172
9	90	173

The part was designed on a flat base of size 80 mm x 40 mm in Solid works. The base was divided into three sections, each being 20 mm long containing different geometric features at exactly same location/distances from the centre of respective section. The geometric features, their intended purpose and their sizes have been tabulated in the Table 2

Table 2 Geometric features included in the benchmark part and their sizes

Feature	Purpose	Number and dimensions (mm)
Base	straightness	1 (80×40×6)
Cube	Parallelism and perpendicularity	1 (20×20×20)
Solid Cylinder	Roundness, cylindricity, accuracy	1(20 mm diameter, 20mm height)
Hollow Cylinder	Roundness, cylindricity and coaxiality of a cylinders	1(outer diameter 20 mm, inner diameter 12 mm, height 20 mm)

Fabrication of bench mark part

The designed benchmarking part was fabricated using Selective Laser Sintering (SLS) process. The part was built using Polyamide powder and the built part is shown in Fig.3. The bench mark parts are produced by changing different process parameters like part build orientation (0°,45°,90°)and part bed temperature(171°C, 172°C, 173°C).

Fig. 3 Benchmark part with different geometric features

To conduct experiments, for each orientation three benchmark parts were produced at three different temperatures. The experimental plan is given in the following Table.

Measurement of geometrical accuracy using CMM

To know the geometric accuracy of parts built by SLS process, there is a necessity to have standardized measurement technique for consistent evaluation. The CMM is suitable for measurement because of its versatility, speed and high accuracy compared to other measurement methods.
CMM was programmed to carry out automatic measurement on the benchmark part to minimise inconsistency that would be incurred with manual measurement. There are various standardised measurements that can be conducted on the benchmark part. These include geometrical tolerances like perpendicularity, parallelism, concentricity etc.

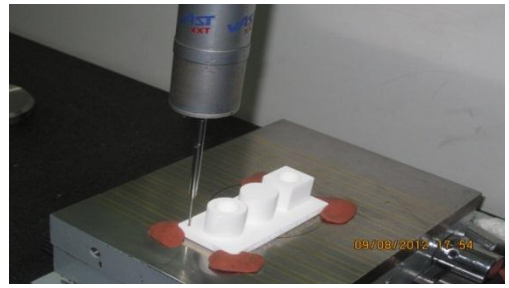

Fig.4 Inspection of the benchmark part on CMM

Results and discussion

Benchmarking parts are produced with different part build orientations and part bed temperatures and they are inspected by CMM to know the different geometric errors like parallelism, perpendicularity, roundness and concentricity. The results of measured geometrical errors of benchmark parts are shown in Table.5

Table 5. Results of different geometric errors of the benchmark part.

Sl. No.	Temp (^{o}c)	Orientation (deg)	Error (mm)								
			Part A				Part B		Part C		
			Pa1	Pa2	Per1	Per2	Rou1	Rou2	Rou1	Rou2	Con
1	171	0	0.0165	0.0385	0.0277	0.0081	0.0403	0.0822	0.0762	0.0505	0.0488
2	172	0	0.0876	0.0365	0.0321	0.0428	0.0377	0.1031	0.0793	0.0603	0.0578
3	173	0	0.1587	0.0345	0.0365	0.0775	0.0351	0.124	0.0824	0.0701	0.0668
4	171	45	0.0602	0.0887	0.1029	0.0979	0.0665	0.0107	0.0239	0.0839	0.0676
5	172	45	0.0631	0.1815	0.1880	0.0815	0.1249	0.0865	0.0993	0.1185	0.1038
6	173	45	0.066	0.2743	0.2731	0.0651	0.1833	0.1837	0.1747	0.1877	0.14
7	171	90	0.0034	0.0885	0.0202	0.0614	0.0007	0.0076	0.0529	0.1463	0.0738
8	172	90	0.0213	0.0761	0.0943	0.0827	0.0130	0.0541	0.0323	0.1475	0.1258
9	173	90	0.0392	0.0637	0.1684	0.104	0.0253	0.1006	0.0117	0.1487	0.1778

Part A: Cube with a circular hole
Pa1: Parallelism 1   Pa2: Parallelism 2

Pr1: Perpendicularity 1   Pr2: Perpendicularity 2

Part B: Solid cylinder

Rou1: Roundness 1

Rou2: Roundness 2

Part C: Hollow cylinder

Rou2: Roundness 2
Con: Concentricity

Results reveal that parallelism error is minimum at 0^{o} part build orientation and at 171^{0}C part build temperature and this is shown in Fig.5 for cube with a circular hole. For solid cylinder roundness error is minimum at 0^{o} part build orientation and at 171^{0}C part build temperature and this is shown in Fig.6. For hollow cylinder concentricity error is minimum at 0^{o}part build orientation and at 171^{0}C part build temperature and this is shown in Fig.7. Also the results reveal that the error increases to maximum as the orientation and sintering temperature is increased from 171^{0}C to 173^{0}C.

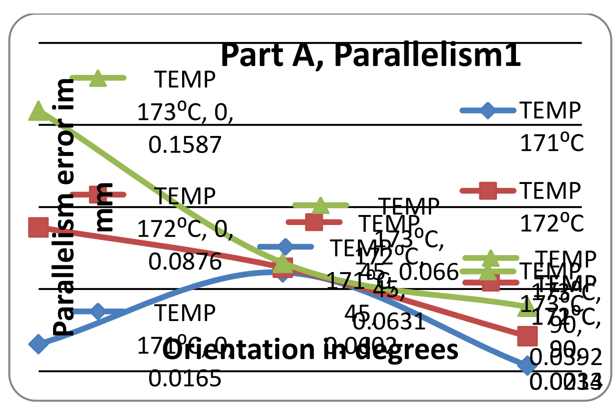

Fig. 5 Effect of orientation angle sintering temperature on parallelism error

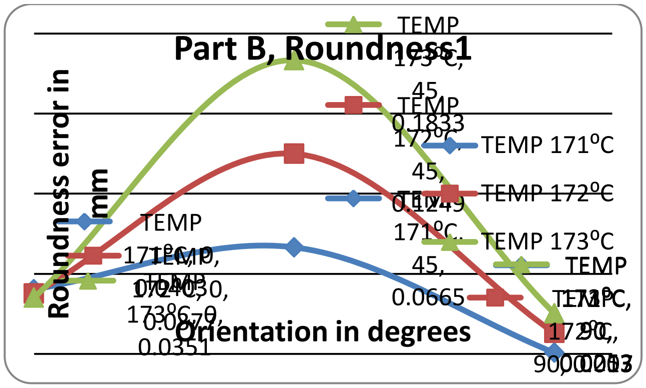

Fig. 6 Effect of orientation angle and sintering temperature on roundness error

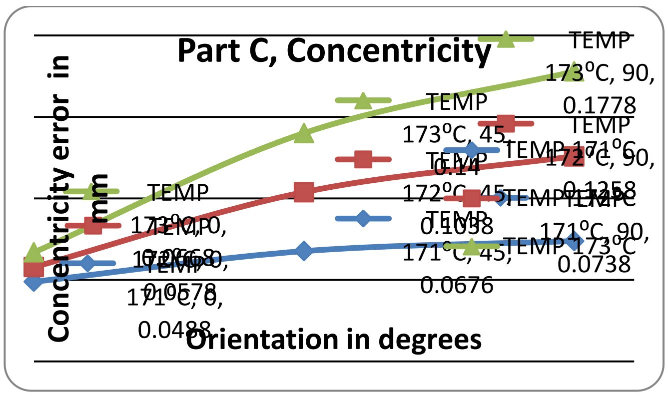

Fig.7 Effect of orientation angle and sintering temperature on concentricity error

Conclusions

In this work studies are carried out to analyze the effect of build orientation and sintering temperature on various geometric errors. Experiments are conducted with different build orientation (0^0, 45^0 and 90^0) and temperatures (171°C, 172^0 C and 173°C). The following conclusions are obtained from the experimental work on SLS machine with polyamide material. In case of a cube with a circular hole, it is found that the parallelism and perpendicularity errors are minimum at 0° orientation and at 171°C part bed temperature. In case of a solid cylinder, it is obtained that the roundness error is minimum at 45° orientation and at 171°C temperature however the build time is more. The concentricity error, in case of a hollow cylinder is minimum at 0° orientation and at 171°C temperature.

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