PROCESS CAPABILITY ANALYSIS OF FUSED DEPOSITION MODELING PROCESS

Santosh Singh Rathor[1], Akash Sharma[1], Yashwant Kumar Modi[2]
[1]Graduate students, Department of Mechanical Engineering, Jaypee University of Engineering and Technology, Guna, India - 473001
rathore.santoshsingh01@gmail.com
akash121709@gmail.com
[2] Faculty in Department of Mechanical Engineering,
Jaypee University of Engineering and Technology, Guna, India – 473001
yashwant.modi@juet.ac.in

ABSTRACT

Additive manufacturing in general and Fused Deposition Modeling (FDM) in particular is capable of fabricating physical parts directly from a Computer-aided design (CAD) model. The fabrication of part takes place without any tooling and free from any geometrical complexity. Nowadays, it is being employed to significantly shorten product development time and cost and to produce parts in small and medium batch. In this study, authors have tried to measure the accuracy and repeatability of the process for the production of prismatic parts to insure that the process is capable enough to produce standard product within its range limit. Process capability analysis is carried out through the computations of various process capability ratios and indices using MINITAB 14.0 software. Initially, a CAD model of a cuboid part with a hole in the center is designed in CAD modeling software. Then twenty specimens have been fabricated on same process parameters. Finally, measurements of linear and diametric dimensions are done on a coordinate measuring machine (CMM). The result shows that dimensions in XY plane are undersized whereas dimension in the Z direction is found oversized. Process capability of the FDM is found approximately 300 micrometers.

The flow of research paper starts with abstract and ends with future work where keywords are followed by abstract then there is an introduction about the topic. Then we talked about process capability and its scope, after which there is experimental work that we carried out. Result and analysis are done on the bases of the experiment.

KEYWORDS: *Additive manufacturing, Fused deposition modeling, STL, CAD, Process capability*

I. INTRODUCTION

Additive manufacturing is also known as rapid prototyping or more popularly 3D printing, is an umbrella term used for a group of manufacturing processes which can produce a part directly from a CAD model by depositing material layer by layer fashion [1, 2]. The first 3D printing process named as Stereolithography was launched in 1986 by 3D systems, USA.3D printing provides enormous flexibility to design engineers due to its inherent nature of layer by layer manufacturing. It can produce models, prototypes as well as end-use part using the variety of materials ranging from paper, wax through plastic, ceramic and composite to metal without needing for any cutting tool. There are several AM processes available in the market today. Fused Deposition Modeling (FDM) is one of the most popular 3D printing processes being used by industries, researchers, offices and even by amateurs[3].

In 1980s technology behind FDM was developed by Scott Crump. He was co-founder and chairman of Stratasys Ltd. which was a leading manufacturer of 3D printers. Various 3D printing organizations have adopted alike technologies in changed names in due course. The New York-based company MakerBot (now possessed by Stratasys), was founded on a nearly identical technology known as fused filament fabrication (FFF) [3] is shipping 44 % of industrial RP systems in the world [4].

In the FDM process, at first, a computer-aided design (CAD) of the part is generated using any solid modeling software. The model is then converted into standard tessellation language (STL) [5,6] that is the *de facto* standard format for rapid prototyping (RP) processes [7]. The translation consists of the approximation of the 3D solid model in unordered triangulated surfaces and the accuracy is decided by setting a maximum chordal error [8]. FDM uses a thermoplastic material in form of wires, which are pre-heated and extruded through a nozzle inside an extruder head. Two different raw material is used in the process; one is used for fabricating the part and another is used as a support material. The extruded material is deposited onto a substrate as per the cross-section of the final part. The extruder head can be moved in Z direction whereas the table can be moved in X and Y directions. Main material and support material are deposited as and when required by the nozzle one by one. The thickness of the layer depends on the nozzle aperture [3]. Usually, printing time depends on the size and complexity of the object to print.

The strength of FDM lies in its capability to fabricate functional parts, user-friendliness, relatively cheaper and more importantly reproducibility [9, 10, 11]. Nevertheless, it is imperfect by a restricted accuracy and poor surface roughness. These flaws can be reduced by controlling software and mechanical aspects. The former is related to the approximation involved in surface tessellation and virtual model slicing, the latter favors the positioning error and the filament solidification hitches, such as irregular shrinkage which causes part distorting [12]. These common manifestations are usually challenging to forecast, therefore users are called to reimburse them by adjusting the process limits through applied experiences. These problems have a direct impact on post-processing cost and functionality of final parts [13, 14]. Since FDM is currently employed in a wide range of applications such as models, functional prototypes, rapid tooling pattern, and fabrication of short series [15,16], the assessments of accuracy and surface roughness of the parts produced becomes inevitable [17]. In this study authors have conducted a process capability analysis of FDM process by fabricating twenty similar parts on same process parameters using Accucraft i250+ Classic Single Extruder in acrylonitrile butadiene styrene (ABS) material [18].

1.1 PROCESS CAPABILITY AND SCOPE

Process capability study is the study of machine or process capability by interpreting and analyzing the information obtained from the process in form of normal curves and control charts. Process capability is defined as the capability of a machine to produce the final part within the specification limits of the product. It compares the range of the product’s dimensions to the standard specification. The basic capability indices generally used in industries are Cp, Cpk, Cpm, and Cpmk [19].

CP-It simply narrates the process capability to the constraint range and it does not relate the position of the process with respect to the specifications. If the value of Cp is equal to or more than 1.33, it is considered that the process is good enough to meet the specifications. While the value of Cp between 1.33 and 1.00 indicate that the process can meet the specifications but require close observation. However, if the value of Cp is below 1.0 then the process is not powerful enough to meet the specification. It does not consider the central tendency of the process with respect to specification limits [19].

CPK- Cpk index dependence on the central tendency of the process. It examines the array with respect to the position of the process. The scale of Cpk relative to Cp is a direct measurement of how off-center the process is operating. It assumes that process output is approximately normally distributed. If the characteristic or process variation is placed between its specification limits, then Cpk and Cp will be equal. On the other hand, as soon as the process variation moves off the specification center, it will depend on the proportion to how far it is offset. Cpk is very worthwhile and very broadly used. Usually, a Cpk equal or greater than 1.33 shows that a process is skillful in the short term. The value less than 1.33 tells that the deviation is either too extensive compared to the specification or that the location of the variation is offset from the center of the specification [19].

CPM - It evaluates process capability about a target. It is always positive in numbers and undertakes that process output is approximately normally scattered. It is also called the Taguchi capability index, which was introduced in 1988. Despite focusing on description limits, Cpm focuses on how well the process means resembles the process target, which may or may not be midway between the specification limits. Cpm is encouraged by Taguchi’s “Loss Function” [19].

CPMK-It evaluate process capability around a target and accounts for an off-center process mean and assumes that process output is approximately normally distributed. The process capability index - Cpk considers process average and evaluates half the process spread with respect to where the process average is actually located, though Cpk takes the process mean into consideration it fails to differentiate an on-target process from the off-target process. The way to address this difficulty is to use a process capability index Cpm that is a better indicator of centering [19].

Dimensional accuracy of a part defines the dependability on the machine to ensure the degree of precision of the final product. The difference between the measured dimension and specified dimension provides an idea about the precision of the machine for mass production of a product. Repeatability is an essential part of manufacturing. The goal of this study is to study the precision and repeatability of Accucraft i250+ Classic Single Extruder (FDM Printer) for short series production. According to existing dimensioning and tolerance standards [4,20], the dimensional accuracy of a component part is evaluated through its size (size tolerance) and shape (geometric tolerance, including form, orientation, and location). In this study, we only concentrated on size variations in length dimension and hole diameter.

II. EXPERIMENT WORK

To conduct the process capability of ABS part fabricated on FDM printer, authors have considered a simple cuboid part with a hole at the center. Three linear dimensions (length, breadth, and height) and one hole diameter was decided to be measured to conduct process capability analysis. First of all, a CAD model of the part (25 mm length, 22 mm breadth, 5 mm thickness and Φ16 mm hole diameter) is generated using Fusion 360^{o} (Student Edition, Autodesk, USA) software as shown in Figure 1.

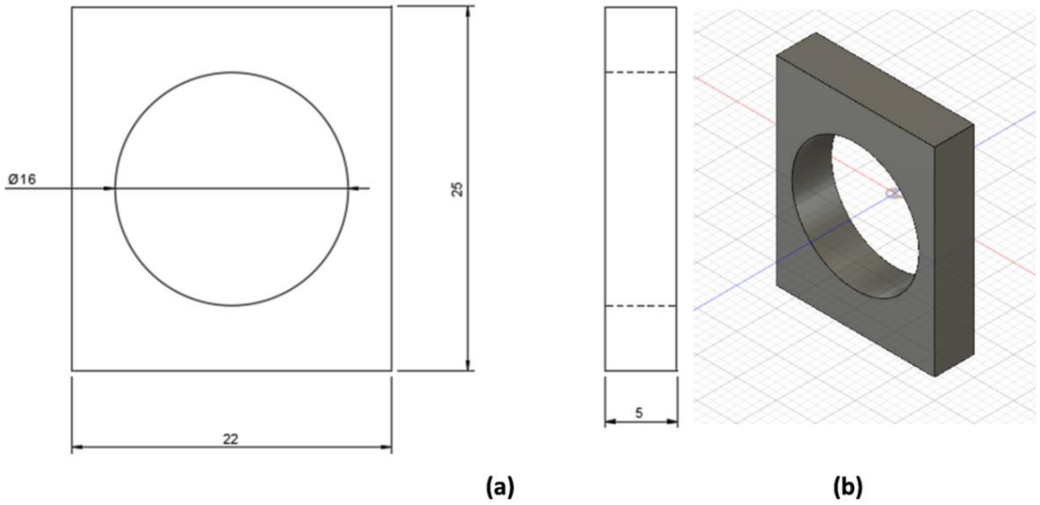

Figure 1 Test specimen (a) Orthographic view (b) CAD model in Fusion 360

Then the CAD model was converted into STL format. The slicing of the STL file was done using KISSlicer software. Finally, the part was fabricated on Accucraft i250+ Classic Single Extruder FDM Printer using ABS material. The part was fabricated with a layer thickness of 0.25 mm and 100 % infill. The part was placed at the center of the build platform as length parallel to X-axis, breadth parallel to Y-axis and height parallel to Z-axis [7].

Total twenty test specimens were fabricated using Accucraft i250+ Classic Single Extruder FDM Printer which has build volume of 300 mm × 250 mm × 200 mm. After fabrication, all three linear dimensions, as well as diameter, have been measured using a coordinate measuring machine manufactured by Helmel Engineering Products, Inc., USA. The probe used was a spherical probe of 3 mm diameter manufactured by Renishaw, UK. Table 1 summaries the average values for three linear and one diametric dimension.

Table 1 Average value of measured dimensions for twenty samples

Sample No.	Length 22mm	Breadth 25mm	Thickness 5mm	Diameter 16mm
1	21.9342	24.9288	5.1949	15.7909
2	21.8641	24.9501	5.2045	15.8588
3	21.8499	25.0147	5.1936	15.8353
4	21.9133	24.9155	5.2141	15.8023
5	21.9008	24.9470	5.2160	15.8062
6	21.8337	24.9249	5.1853	15.8566
7	21.9274	24.9818	5.2069	15.8336
8	21.8832	24.9479	5.2305	15.8804
9	21.8582	24.9024	5.1821	15.8666
10	21.9058	25.0070	5.2173	15.8460
11	21.9049	24.9975	5.1804	15.8232
12	21.8422	24.9060	5.1998	15.8296
13	21.8720	24.8647	5.2034	15.7893
14	21.8984	24.8480	5.1851	15.8396
15	21.8942	24.9358	5.2034	15.8228
16	21.8717	24.9081	5.2141	15.8297
17	21.8619	24.9650	5.1663	15.8310
18	21.8269	24.9874	5.2014	15.8214
19	21.9011	24.9871	5.2133	15.7713
20	21.8799	24.9524	5.1777	15.8176

III. RESULTS AND ANALYSIS

The variation in particular dimensions among different specimens have been shown in Figure 2 to 5 using X-bar and R-charts plotted in MINITAB 14 software.

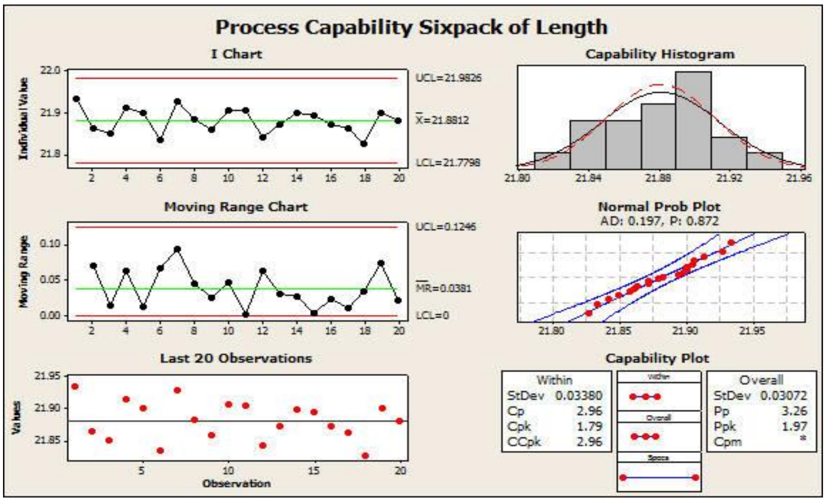

Figure 2 Control charts, capability histogram and normal probability plot for length

It is significant to note that all the dimensions in the XY plane, i.e. length (along X- direction) and width (along Y-direction) are underdeveloped. On the other hand, the dimension in the Z direction, i.e. height was oversized. Also, the usual error for the height was about two to three times higher than the average error for dimensions in the XY plane.

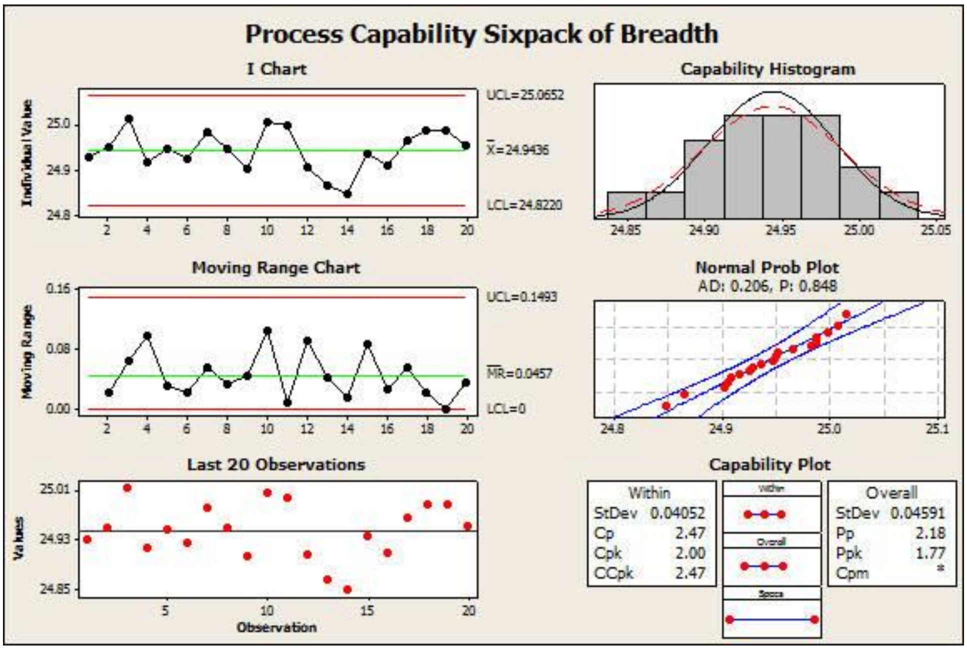

Figure 3 Control charts, capability histogram and normal probability plot for breadth

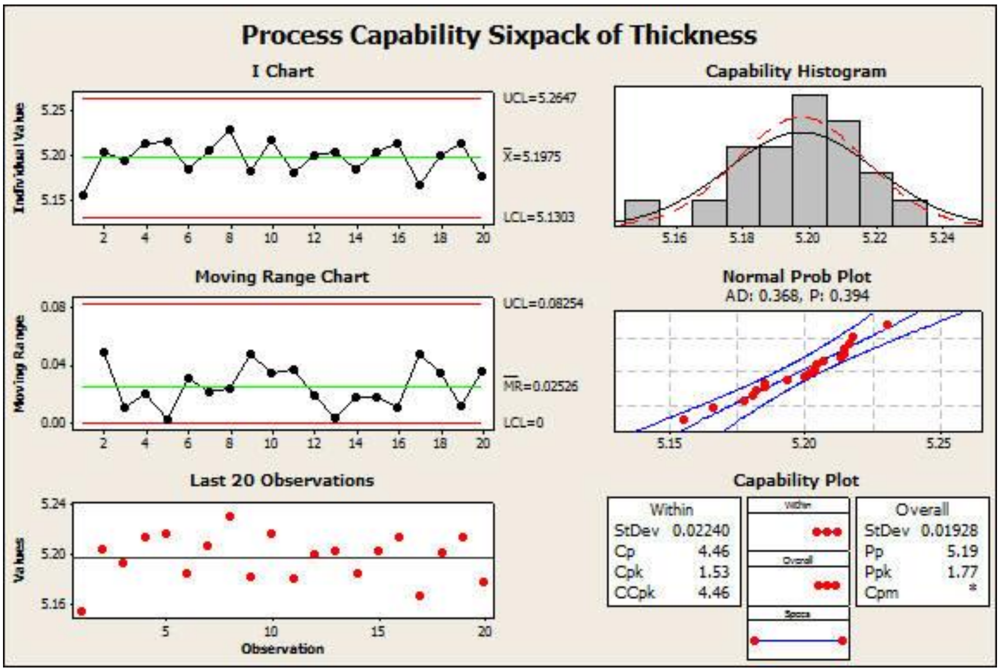

Figure 4 Control charts, capability histogram and normal probability plot for thickness

It is understood that under sizing of linear dimensions in the XY plane is characteristic in the 3D printing process as the binding fluid experience shrinkage when comes in interaction with the raw material powder. The oversizing of height is supposed to be caused by the incremental construction error of the build table's vertical movement. The variation in the hole diameter is given in Figure 6. The hole diameter was also measured in XY plane and displays similar trend as in the length dimensions i.e. the holes are undersized.

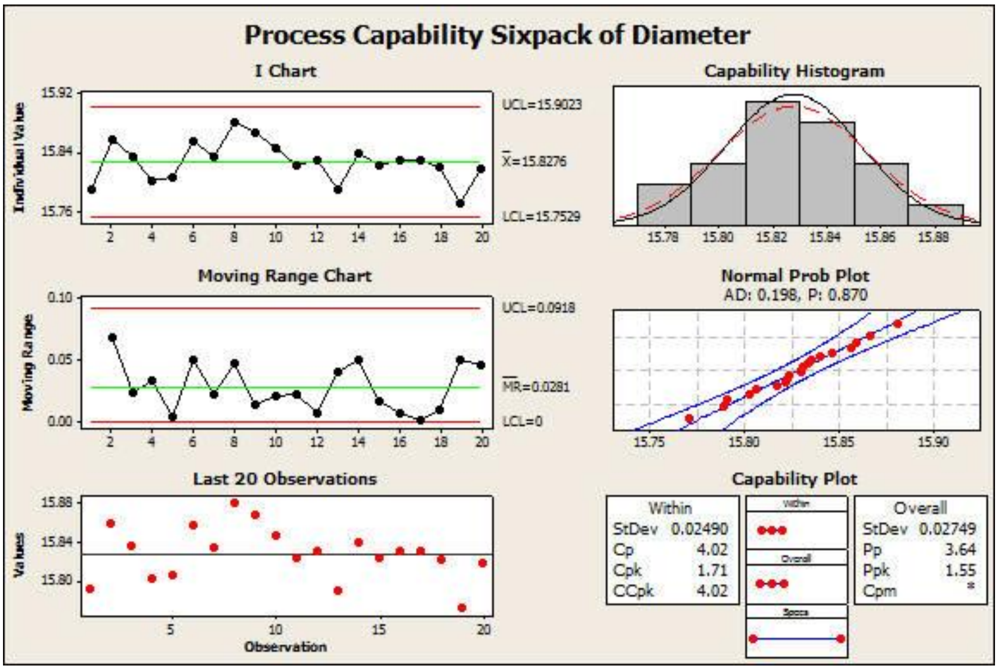

Figure 5 Control charts, capability histogram and normal probability plot for diameter

Process capability of different dimension has been calculated using MINITAB 14 software, which is more than 1.33, the minimum allowable value of C_p and C_{pk} in industries. Various other indices are also measured in the process are shown in Figure 6.

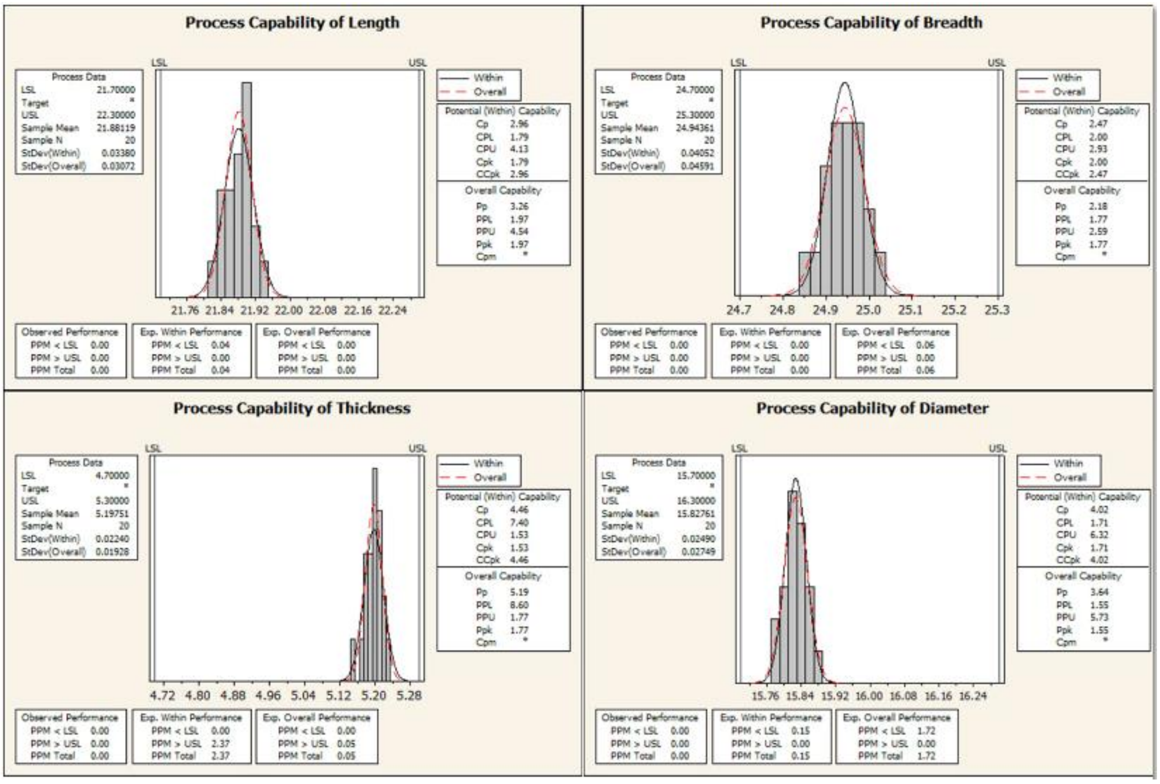

Figure 6 Process Capability of analysis of various dimensions

Upon comparison among Figure 2 to 5, it appears that the variation in errors (±3σ) for the hole diameter is greatest among all the four dimensions. It may be due to the layered printing process and the contraction due to the binding action between the build powder and the binding liquid. The first layer is free to diminish, and as a result, the maximum shrinkage occurs at this stage and yields the smallest hole-diameter. Once the next layer is printed, its narrowing is limited by a printed layer, causing in less contraction. The process lasts as further layers are printed. The last layer contracts by the minimum amount, resulting in the largest diameter but still slightly undersized.

IV. CONCLUSIONS

In this study, process capability analysis of FDM printer for fabricating thermoplastic component has been carried out. FDM printers are becoming very popular nowadays and their strength and weaknesses need to be ascertained through process capability analysis [21].. The dimensions in the horizontal plane are found to be slightly undersized whereas dimension in the vertical direction is slightly oversized. The process capability (6σ) is found approximately 300 micrometers. FDM can be used to produce parts in the short production run. The process also proves suitable for the conceptual models and new product development where cost and time for production of dies and tool are high. This process can significantly reduce the time and cost in such cases. The results are in line with the observations made by other investigators [21].

V. FUTURE WORK

Process Capability of 3D printers is essential in today’s world. We will carry out process capability on various other combinations of materials and process used in 3D modelling. As the use of 3D printers is increasing day by day, our study will be help in choosing best process in terms of accuracy and capability for mass production of different objects of any material.

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AUTHORS

Santosh Singh Rathore: Completed B.Tech in Mechanical Engineering from Jaypee University of Engineering and Technology, Guna, MP, India [473001] in 2016 and currently he is an aspiring student to pursue master's in design and fabrication (mechanical) from the United States of America.

Akash Sharma: Completed B.Tech in Mechanical Engineering from Jaypee University of Engineering and Technology, Guna, MP, India [473001] in 2016.

Dr. Yashwant Kumar Modi: Assistant Professor in the Department of Mechanical Engineering, Jaypee University of Engineering and Technology, Guna, MP, India -473001.