International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

OPTIMISATION OF PROCESS PARAMETERS IN RAPID PROTOTYPING FOR NYLON POLYAMIDE MATERIAL

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ABSTRACT

Rapid Prototyping (RP) is finding applications in diverse fields in the industry today, with prototypes used for form, fit and function. Design Engineers around the world use Rapid Prototyping to pre-estimate product characteristics like shape, manufacturability and finish. Due to the excellent advantages of rp, it is fast catching the fancy of large number of people. A functional part of any manufacturing technique possess quality characteristics and they largely depend on process parameters. For the rapid prototyping technique, Selective Laser Sintering, process parameters and their interactions are optimized to gain quality characteristics.

I INTRODUCTION

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereolithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available.

Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

There is a multitude of experimental RP methodologies either in development or used by small groups of individuals. This section will focus on RP techniques that are currently commercially available, including Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), 3D printing, and Ink Jet printing techniques.

II SELECTIVE LASER SINTERING

2.1. Introduction

Among the different RP processes the SLS process has gained traction in the manufacturing industry due to its capability to produce complex parts of any geometry without the need for special tooling and support structures.

SLS also able to manufacture parts from materials such as metal and nylon which are difficult to fabricate using traditional methods.

2.2 Description

In this case, however, a laser beam is traced over the surface of a tightly compacted powder made of thermoplastic material (A). The powder is spread by a roller (B) over the surface of a build cylinder (C). A piston (D) moves down one object layer thickness to accommodate the layer of powder.

The powder supply system (E) is similar in function to the build cylinder. It also comprises a cylinder and piston. The piston moves upward incrementally to supply powder for the process.

Heat from the laser melts the powder where it strikes under guidance of the scanner system (F). The CO2 laser used provides a concentrated infrared heating beam. The entire fabrication chamber is sealed and maintained at a temperature just below the melting point of the plastic powder. Thus, heat from the laser need only elevate the temperature slightly to cause sintering, greatly speeding the process. A nitrogen atmosphere is also maintained in the fabrication chamber which prevents the possibility of explosion in the handling of large quantities of powder

After the object is fully formed, the piston is raised to elevate the object. Excess powder is simply brushed away and final manual finishing may be carried out. It may take a considerable time before the part cools down enough to be removed from the machine. Large parts with thin sections may require as much as two days of cooling time

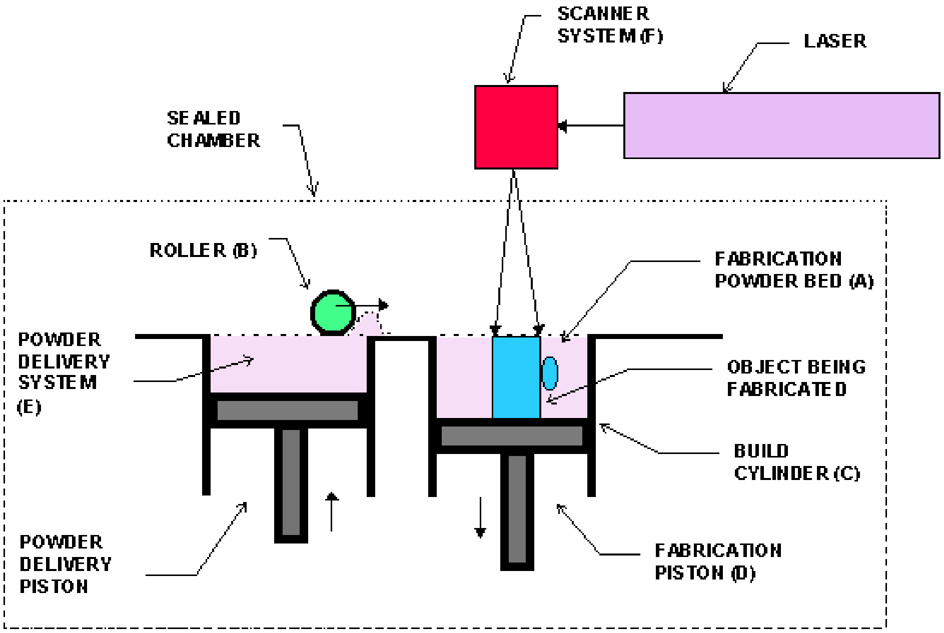


Fig 3.5: Selective Laser Sintering

No supports are required with this method since overhangs and undercuts are supported by the solid powder bed. This saves some finishing time compared to stereolithography. However, surface finishes are not as good and this may increase the time. No final curing is required as in stereolithography, but since the objects are sintered they are porous. Depending on the application, it may be necessary to infiltrate the object with another material to improve mechanical characteristics. Much progress has been made over the years in improving surface finish and porosity. The method has also been extended to provide direct fabrication of metal and ceramic objects and tools.

2.3 Process Parameters

When preparing to build SLS parts, many fabrication parameters are needed in the software. To achieve optimum quality, these parameters are set differently according to requirements of applications. Therefore, the first step in the experiment was to identify the process control parameters that are likely to affect the quality of SLS parts. Various process parameters are layer thickness, raster angle, air gap, bead width, model temperature.

Here in our experiment Build orientation is the only parameter changed.

2.4 Description about materials

Nylon Polyamide is the material used in the Rapid prototyping process.Following is the description about materials used here.

Properties:

The majority of nylons tends to be semi-crystalline and is generally very tough materials with good thermal and chemical resistance. The different types give a wide range of properties with specific gravity, melting point and moisture content tending to reduce as the nylon number increases.

Nylons tend to absorb moisture from their surroundings. This absorption continues until equilibrium is reached and can have a negative effect on dimensional stability.

In general, the impact resistance and flexibility of nylon tends to increase with moisture content, while the strength and stiffness below the glass transition temperature (< 50-80°C) decrease. The extent of moisture content is dependent on temperature, crystalline and part thickness. Preconditioning can be adopted to prevent negative effects Nylons tend to provide good resistance to most chemicals, however can be attacked by strong acids, alcohol sand alkalis. Nylons can be used in high temperature environments. Heat stabilized systems allow sustained performance at temperatures up to 185 °C (for reinforced systems).

2.5 PA2200

a. Application

PA2200 is suitable for use in all EOS systems with fine polyamide option. The recommended layer thickness is 0.15mm. Unexposed powder can be reused. Depending on the building time it has to be mixed with fresh powder by a ratio of 2:1 to 1:1 (old: new) in order to guarantee constant process parameters and persisting part quality.

Typical applications of the material are fully functional prototypes with high end finish right from the process. They easily can with stand high mechanical and thermal load.

b. Material properties

Average grain size	60	µm
bulk density	0.435 - 0.445	gm/cm3
Density of laser sintered part	0.9 - 0.95	gm/cm3

c. Mechanical Properties

Tensile modulus	1700 ± 150	N/mm2
Tensile strength	45 ± 3	N/mm2
Elongation at break	20 ± 5	%
flexural modulus	1240 ± 130	N/mm2
Charpy - Impact Strength	53 ± 3.8	kJ/m2
Charpy - Notched Impact Strength	4.8 ± 0.3	kJ/m2
Izod - Impact strength	32.8 ± 3.4	kJ/m2
Izod - Notched Impact Strength	4.4 ± .4	kJ/m2
Ball Indentation hardness	77.6 ± 2	
Shore D - Hardness	75 ± 2	

2.6 Linear Regression

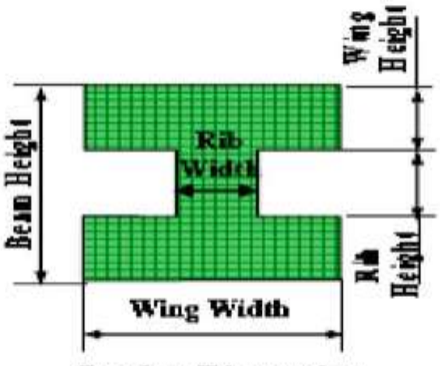
Linear regression was the first type of regression analysis to be studied rigorously, and to be used extensively in practical applications. This is because models which depend linearly on their unknown parameters are easier to fit than models which are non-linearly related to their parameters and because the statistical properties of the resulting estimators are easier to determine.

In statistics, linear regression is an approach to model the relationship between a scalar dependent variable y and one or more explanatory variables denoted X. The case of one explanatory variable is called simple linear regression. For more than one explanatory variable, it is called multiple linear regression. (This term should be distinguished from multivariate linear regression, where multiple correlated dependent variables are predicted,[citation needed] rather than a single scalar variable.)

III EXPERIMENTATION

A trial run was performed in which a series of samples were built in th method of rapid prototyping. They are FORMIGA P 100 SLS – RP System

The sample taken is a simple I section and is as shown in figure.



Section Dimension

Dimensions are as follows:

	SLS
Beam Height	50
Wing Width	30
Wing Height	10
Rib Width	10
Rib Height	30
Thickness	10

All dimensions are in mm.

3.1 Analysis:

Regression analysis was used in this work in order to evaluate the relative contribution of process parameter on various characteristics like

a. Dimensional accuracy, b. Surface quality, c. Density, d. Tensile strength, e. Hardness

Part accuracy:

Minimum deviation between fabricated part dimension and CAD model dimension was selected as one of the part accuracy criteria. To measure the deviation each dimension is studied separately. For finding the deviation each and every dimension of the fabricated part is measured using micrometer. The least count of micrometer are 0.01 and 0.001mm respectively.

Surface Quality:

Roughness values on the surface of the samples were obtained using surf test, a contact type of measuring instrument and the Ra values are noted. Each measurement is taken a length of over 4 mm.

Density:

Density of every model is calculated using weight and volume measurement.

Hardness:

Hardness of each and every model is calculated using Rockwell hardness tester for hardness.

Tensile strength:

Tensile strength of models of sls are tested using universal tensile machine.

For SLS a total of 4 samples are made. Here only part orientation is the only process parameter changed and their levels are as below.

LEVEL	PART ORIENTATION
1	0
2	10
3	20
4	30

Here the material used is Nylon Polyamide PA2200.

The screen shots regarding this process are shown below.

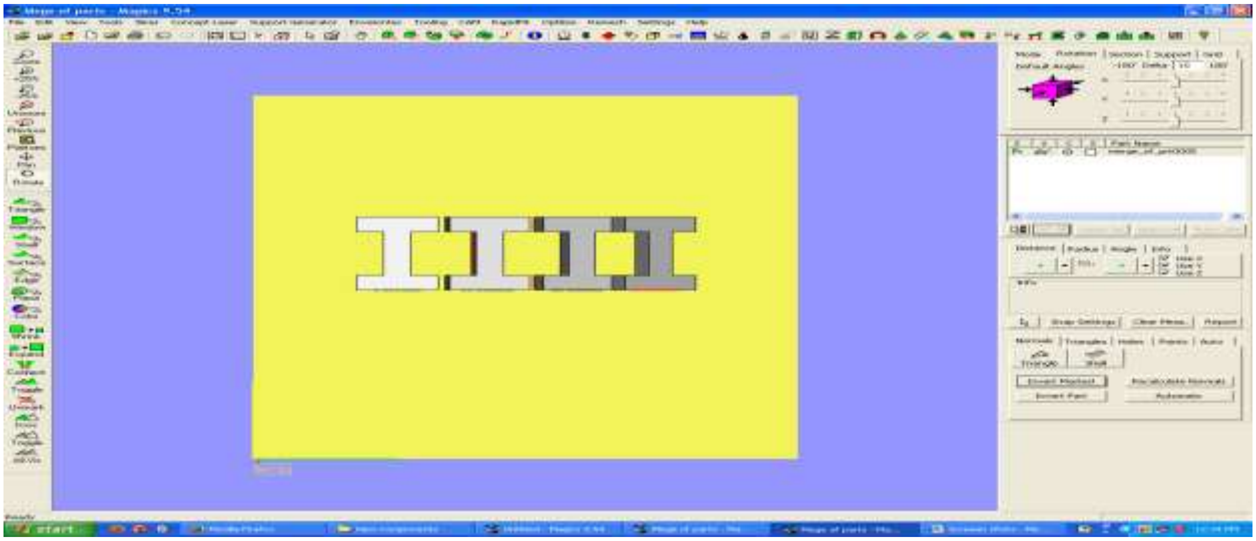


Fig 4.4:Top view of models in SLS

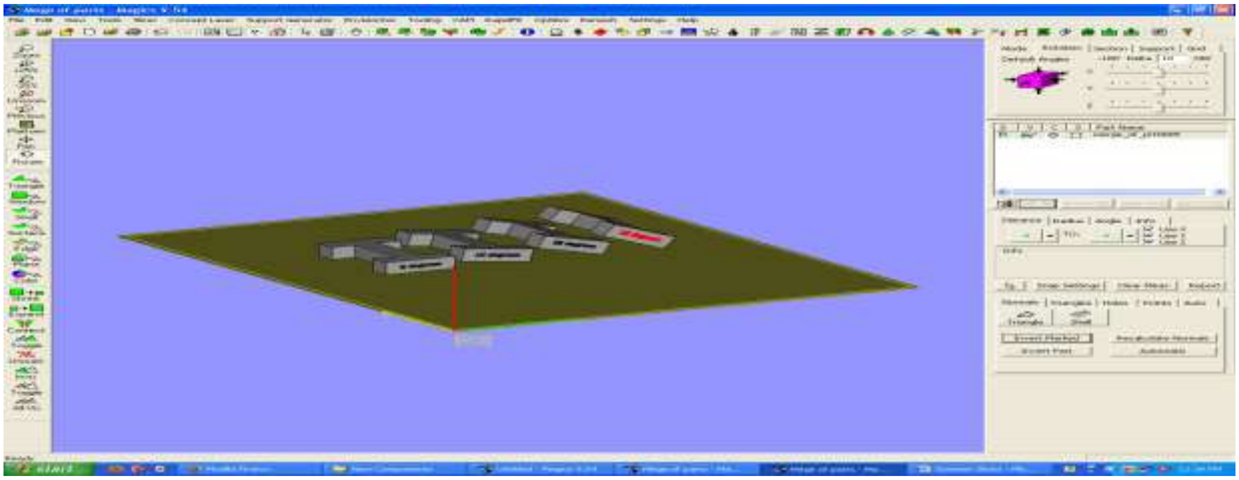


Fig 4.5: Front view of models in SLS

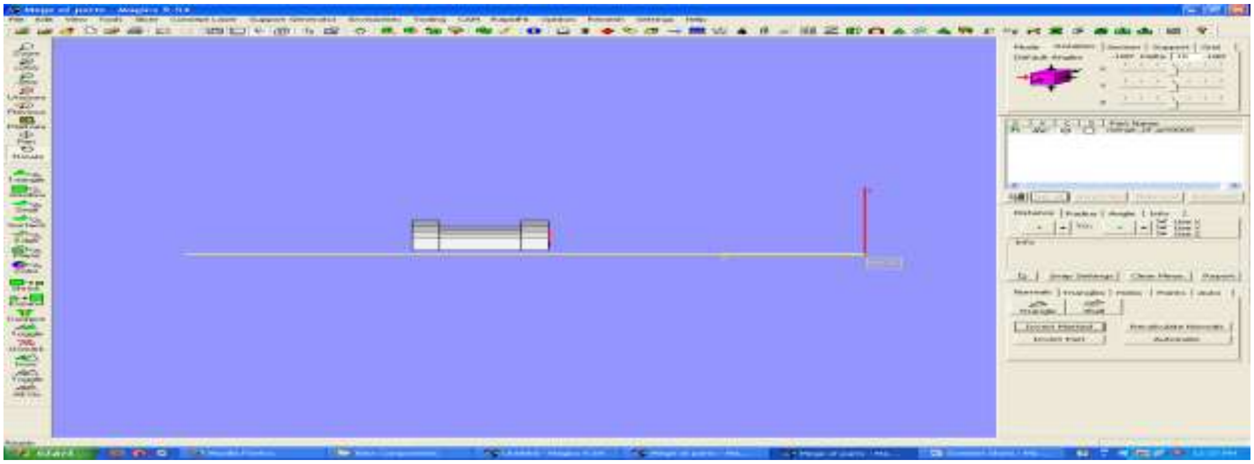


Fig 4.6: Side view of models in SLS

Fig 4.7: Sintering of models in SLS

Analysis:

Simple linear Regression and ANOVA was used for this process in order to evaluate the relative contribution of process parameter on various characteristics like

a. Dimensional accuracy

b. Surface quality

c. Density

d. Tensile strength

e. Hardness

Following shows the output for all the above factors.

Dimensional Accuracy:

Regression Statistics	
Multiple R	0.979217
R square	0.958865
Adjusted R square	0.938298
Standard Error	0.001703
Observations	4

ANOVA:

Factor	Dof	SS	MS	F	Significance F
Regression	1	0.00013	0.00013	46.6206	0.020783
Residual	2	5.8E-06	2.9E-06		
Total	3	0.00014			

	Coefficients	Std Error	T Stat	P Value	Lower 95%	Upper 95%
Intercept	49.5293	0.01425	34762.75	8.28E-10	49.52317	49.5348
Angle	-0.00052	7.62E-05	6.82793	0.020783	0.00085	0.00019

Surface Quality:

Regression Statistics	
Multiple R	0.6129
R square	0.374777

Adjusted R square	0.032165
Standard Error	02.36284
Observations	4

ANOVA:

Factor	Dof	SS	MS	F	Significance F
Regression	1	6.693245	6.693245	1.198859	0.38781
Residual	2	11.16603	5.583015		
Total	3	17.85928			

	Coefficients	Std Error	T Stat	P Value	Lower 95%	Upper 95%
Intercept	15.418	1.976894	7.799102	0.01604	6.912111	23.92389
Angle	-0.1157	0.105669	1.09492	0.38781	0.338959	0.338959

Density:

Regression Statistics	
Multiple R	0.96601
R square	0.933175
Adjusted R square	0.899762
Standard Error	0.021587
Observations	4

ANOVA:

Factor	Dof	SS	MS	F	Significance F
Regression	1	0.013015	0.013015	27.92878	0.03399
Residual	2	0.000932	0.000466		
Total	3	0.013947			

	Coefficients	Std Error	T Stat	P Value	Lower 95%	Upper 95%
Intercept	9.32348	0.018061	516.2137	3.75E-06	9.245769	9.245769
Angle	-0.0051	0.000965	5.28477	0.0399	-0.00926	0.00095

Tensile Strength:

Regression Statistics	
Multiple R	0.138943
R square	0.019305
Adjusted R square	-0.47104
Standard Error	11.26943
Observations	4

ANOVA:

Factor	Dof	SS	MS	F	Significance F
Regression	1	5	5	0.03937	0.861057
Residual	2	254	127		
Total	3	259			

	Coefficients	Std Error	T Stat	P Value	Lower 95%	Upper 95%
Intercept	230	9.42868	24.39366	0.001676	189.4317	2705683
Angle	-0.1	0.503984	-0.19842	0.861057	-2.26847	2.068469

Hardness:

Regression Statistics	
Multiple R	0.989949
R square	0.98
Adjusted R square	0.97
Standard Error	0.632456
Observations	4

ANOVA:

Factor	Dof	SS	MS	F	Significance F
Regression	1	39.2	39.2	98	0.010051
Residual	2	0.8	0.4		
Total	3	40			

	Coefficients	Std Error	T Stat	P Value	Lower 95%	Upper 95%
Intercept	12.8	0.52915	28.18973	0.001705	105235	15.0765
Angle	0.28	0.28284	90899495	0.010051	0.158303	0.401697

IV RESULTS AND DISCUSSIONS

SELECTIVE LASER SINTERING:

4.1 Dimensional Accuracy:

1. 95% of variation in dimensional accuracy is explained by variation in part orientation.
2. Since p value is less than the confidence level part orientation effects Dimensional accuracy.
3. From f test also we can say orientation has its effect.

4.2 Surface Finish:

1. Only 37% of variation in surface finish is explained by variation in part orientation.
2. P value is more than the confidence level part orientation does not effect surface finish.
3. From F test we can say that orientation effect is negligible.

4.3 Density:

1. 93% of variation in density is explained by variation in part orientation.
2. P value is less than the confidence level part orientation effects density.
3. From F test we can say that orientation effect is considered.

4.4 Hardness:

1. 98% of variation in hardness is explained by variation in part orientation.
2. P value is less than the confidence level part orientation effects density
3. From F test we can say that orientation effect is considered

4.5 . Tensile Strength:

1. Only 2% of variation in Tensile Strength is explained by variation in part orientation.
2. P value is more than the confidence level part orientation does not effects surface finish.
3. From F test we can say that orientation effect is negligible.

These results are subjected to particular dimensions only. If any particular changes in dimensions may vary the results.

V CONCLUSIONS

The conclusions drawn from the results and analysis of SLS process are shown in the following tabular forms:

	CHARACTERISTICS				
PROCESS PARAMETER	DIMENSIONAL ACCURACY	SURFACE FINISH	DENSITY	HARDNESS	STRENGTH
PART ORIENTATION	effects	Does not effect	Effects little	effects	Does not effect

VI FUTURE SCOPE OF STUDY

Further work can be extended to

1. Other mechanical properties like flexural strength, compressive strength, etc.
2. Thermal properties.
3. Quality characteristics like production time cost.
4. Other type of cross sections
5. Other type of process parameters.

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