

Systematic Analysis of Rapid Prototyping Machines to Enhance the Productivity and to Minimize the Cost of Raw Material and Production

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Abstract- In recent years, rapid prototyping technology (RPT) has been implemented in many spheres of industry, particularly in the area of product development. Existing processes provide the capability to rapidly produce a tangible solid part, directly from three dimensional CAD data from a range of materials such as photo curable resin, powders and paper. This paper gives an overview of the growth and trend of the technology, areas of applications. Although digital modeling and analysis methods are widely employed at various product development stages, still, building a physical prototype makes the present typical process expensive and time consuming. Therefore, it is necessary to implement new technologies, such as virtual prototyping, which can enable industry to have a rapid and more controlled decision making process.

Keywords- Rapid prototyping, product development, manufacturing.

I. INTRODUCTION

Rapid Prototyping (RP) is a process which fabricates a part layer-by-layer. This technology has also been referred to as layered manufacturing, additive manufacturing, and rapid manufacturing. Rapid prototyping automatically generates physical objects directly from 3D CAD data by depositing material layer by layer, unlike conventional methods, where material is removed to obtain the final object.

Fundamentally, the development of Rapid Prototyping technology can be split into four primary aspects: Input, Method, Material, and Applications. Input refers to the electronic information required to describe the physical object with numerical data. In the last decade, a number of techniques for Rapid Prototyping have been developed. There are several methods employed in different Rapid Prototyping systems.

II. LITRATURE REVIEW

[1] Virtual Prototyping is an advanced and prevailing virtual simulation tool enabling rapid product development. It was implemented primarily by large automotive, aerospace and shipbuilding industries. Visualization of the Boeing 777, the first large aircraft built without the construction of a physical mockup, was done with a package named FlyThru. Boeing research has also created a series of experiments to investigate the advantages of VR, together with its use for maintainability analysis. [Ali Ahmed].

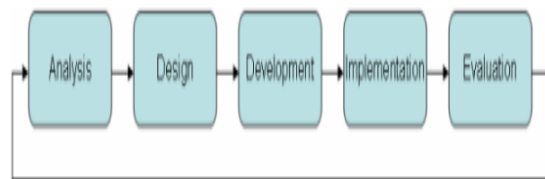


Fig 1. Block diagram of rapid prototyping process.

Material addition technologie	Processes involving liquid	Stereo lithography (SLA) Liquid thermal polymerization (LTP) Beam interference solidification (BIS) Solid ground curing (SGC) Holographic interference solidification (HIS) Electro setting (ES) Ballistic particle manufacture (BPM) Fused deposition modeling (FDM) Three dimensional welding (3DW) Shape deposition manufacturing (SDM)
	Processes involving discrete particles	Fusing of particles by laser Selective laser sintering (SLS) Gas phase deposition (GPD) Joining of particles with a binder Three dimensional printing (3DP) Spatial forming (SF)
	Technologie which use solid	Laminated object manufacture (LOM) Solid foil polymerization (SFP)

Material removal technology		Desktop milling (DM)
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[2] Tripp and Bichelmeyer (1990) define a model that occurs in a rapid prototyping environment, when prototyping is specifically used as a method for instructional design. The overlapping boxes are meant to represent the fact that the various processes do not occur in a linear fashion. In other words, the analysis of needs and content depends in part upon the knowledge that is gained by actually building and using a prototype instructional system.” [Gay boulet].

[3] In 1997, D.T. Pham and R.S. Gault [7] presented and summarized different rapid prototyping technologies. The paper presented an overview of rapid prototyping technologies and commented on their strengths and weaknesses. In this study, data such as layer thickness, system accuracy and speed of operations were given.

III. CURRENT RP SYSTEMS USED FOR ANALYSIS

1. Selective Laser Sintering (SLS):

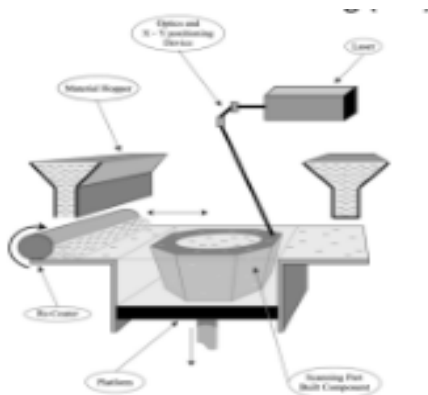


Fig 1. Schematic view of SLS process.

The Selective Laser Sintering (SLS) process produces solid components using a carbon dioxide (CO₂) laser to heat powdered materials layer by layer so that the surface tensions of the grains are overcome and they fuse together. Before the powder is sintered, the entire chamber is heated to just below the melting point of the material in order to minimize thermal distortion and facilitate fusion to the previous layer [5]. The laser selectively fuses powdered materials by tracing the cross-sectional slices from a 3D digital description of the part.

The interaction of the CO₂ laser beam with the powder raises the temperature to the melting point, resulting in particle bonding, fusing the particles to themselves and the previous layer to form a solid [1]. The laser beam with adjustable intensity fuses the powder only in areas defined

by the part’s geometry. The powder not melted or fused during processing serves as support structure. Therefore, there is no need to have support material in the SLS process. After each cross-section is completely drawn, the powder bed is lowered by one layer thickness, and an additional layer of powder is deposited via a roller mechanism on top of the previous layer. The process: (1) new layer deposited, (2) laser beam trace, and (3) entire powder bed lowered is repeated until the part is complete.

2. Fused Deposition Modeling (FDM):

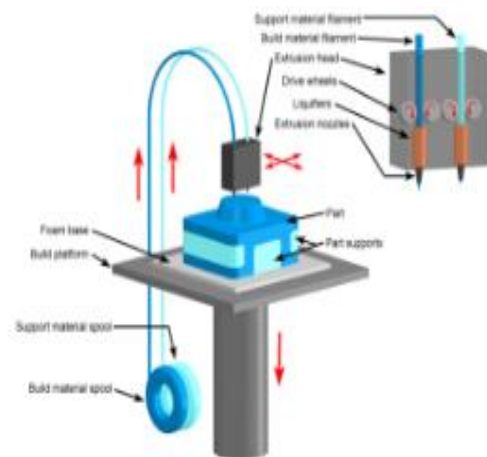


Fig 2. Schematic view of FDM process.

Scott Crump, the president and CEO of Stratasys Inc., developed the Fused Deposition Modeling (FDM) process in 1988 and the patent was awarded in the U.S. in 1992 [1, 3]. The FDM process fabricates parts by extruding semi molten material through an extrusion head that traverses in X axis and Y axis to create each two dimensional layer of the part [10]. The movable extrusion head composed of two extrusion nozzles: one for build material and the other for support material [1, 7, and 11]. This process can be seen in Figure 3.

The extrusion head deposits a filament of molten material either build material or support material onto a foam base. The build material is heated to 0.5°C above its melting point so that it solidifies about 0.1s after extrusion and cold welds to the previous layers [7]. In general, an outline of the perimeter of the part is extruded from the head first and then the interior is raster filled by the extruder head [10]. Once a layer is built, the platform lowers, and the extrusion head deposits another layer. The machine continues to build the part layer by layer until it is complete. When the part is finished, it is removed from the machine and the support material need to move away to reveal the finished product.

There are two types of support material: Soluble support system and Break-Away Support System (BASS) [12]. It can be removed with specialized

equipment utilizing water-based sodium 9 hydroxide solution, or break it away by hand.

IV. METHODOLOGY

Table 2. Materials and sample preparation.

System	Material	Machine setting
FDM	ABSplus-P430 (ABS plastic)	Default Model interior fill = Sparse - High density Support Fill = Sparse Z-Axis = 0.007 inch (0.1778 mm)
SLS	PA 2200 Balance 1.0 (polyamide 12)	Default Standard calibration for PA2200 Z Axis = 0.100 mm

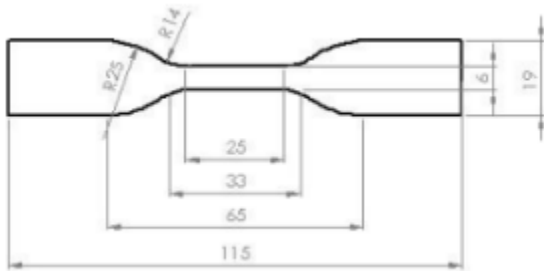


Fig 3. Shape of test specimen.

1. Tensile testing:

Tensile tests were performed on a universal testing machine equipped with a 10 KN load cell. All the tests were conducted at the same temperature of 72°F.

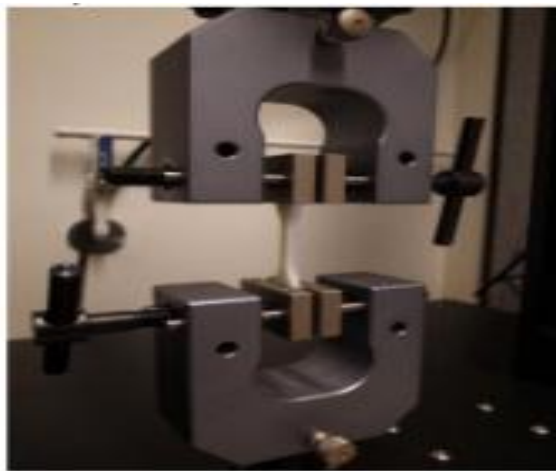


Fig 4. The test specimen is clamped by the jaws of the test machine.

2. Water Absorption:

The Horizontal build orientation was chosen to make specimens for investigating the relative rate of water absorption by plastics when immersed. The reason to choose Horizontal build orientation was the shortest machine duration compared with Side and Vertical. For the water absorption investigation, the independent variable was the specified rapid prototyping system and its relative material used, and the dependent variable was the weight change when water absorbed. The independent variable, build orientations, was not included in this investigation. Two specimens were made in each of four rapid prototyping systems.

Prior to infiltration, all specimens were sealed in a zip lock plastic bag for one week (168 hours) at the same environment condition. This step kept all specimens under the same environment condition and decreased experimental errors. When the desired time was reached, all specimens were immediately measured for the initial weight. The specimens were placed in a container of distilled water maintained at a temperature of 72 ±1°F and entirely immersed for 24 hours.

When the desired time was reached, the specimens were then taken out, wiped gently with a dry tissue paper and weighed immediately. The specimens were weighed using a precision balance. Percentage of moisture absorption was calculated based on the weight change.

Equation 1:

$$\text{Water absorption (percent)} = \frac{[\text{Weight after conditioning for 24 hours (g)} - \text{initial weight (g)}]}{\text{initial weight (g)}} \times 100$$



Fig 5. Specimens for water absorption sealed in a plastic bag.

Microscopy:

A stereo microscope, MEIJI Techno EMZ-5TR equipped with MA502eyepieces as shown in Figure 13, was used to capture magnified photographs from the specimens after tensile properties testing to investigate their internal structure. The magnification capability is 7 times to 45 times. A digital camera, Moticam 10, was used to connect

the stereo microscope and capture large scale images for documentation purposes.

The software, Motic Images plus 2.0, was used to capture JPEG images as a multi-media demonstration platform. All specimens made for tensile testing in three build orientations in SLS, FDM, systems were examined using the stereo microscope to observe their fractured surface.



Fig 6. Stereo Microscope.

V. RESULTS AND ANALYSIS

1. Dimensional Accuracy:

Equation 2:

$$\text{Dimension Change Rate (percent)} = \frac{[\text{Measured value (mm)} - \text{Desired value (mm)}]}{\text{Desired value (mm)}} \times 100$$

Equation 3:

$$\text{Dimensional Accuracy (percent)} = \frac{|\text{Measured value (mm)} - \text{Desired value (mm)}|}{\text{Desired value (mm)}} \times 100$$

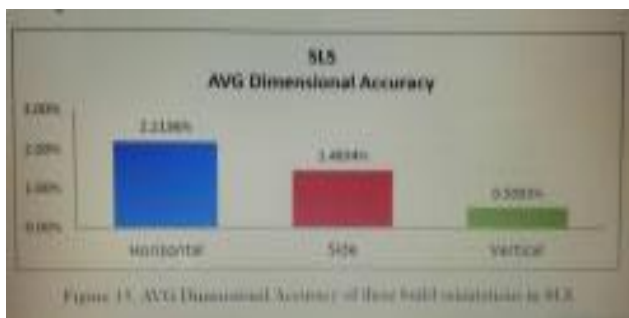


Figure 15. AVG Dimensional Accuracy of three build orientations in SLS



Figure 16. AVG Dimensional Accuracy of three build orientations in FDM

Fig 7. Dimensional accuracy graph.

Tensile strength of materials for different machines:

Table 3. Observation Table.

RP System		Machine type	
Build Orientation		SLS	FDM
Tensile Strength (psi)	AVG	7367.4	7122.8
	SD	27.364	107.816
Elongation (%)	AVG	7.4545	7.3296
	SD	0.4283	0.1661
Elongation at Break (%)	AVG	16.5334	15.7361
	SD	1.2306	0.4489

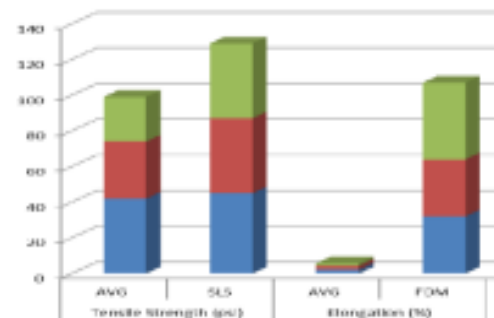


Fig 8. Graph of tensile strength.

Water absorption rate of different rapid prototype machines:

Table 4. Observation Table.

RP Type	Weight (g)		relative rate of Water Absorption
	Before	After	
SLS	6.83	6.54	1.600
FDM	7.70	7.75	1.1688

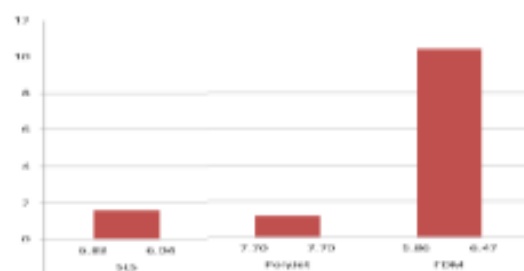


Fig 9. Graph of Absorption

VI. CONCLUSION

Through analysis of this comparative study, rapid prototyping users interested in optimizing production will have an idea of the effect on dimensional accuracy and tensile properties of different build orientations and RP technologies, as well as the effect of different RP technologies on water absorption and the ductility of raw material. In addition, this can be a stepping-stone for further investigation of rapid prototyping technologies.

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