Rapid Prototyping Technology- Classification and Comparison

Dharipalli Hyndhavi[1], S.Bhanu Murthy[2]

[1]M.Tech Student, Mechanical Engineering Department, VNRVJIET, Hyderabad, India.
[2]Assistant Professor, Mechanical Engineering Department, VNRVJIET, India.

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Abstract - *Rapid Prototyping is a group of techniques used to quickly fabricate a prototype, develop a product of high quality, low cost in shortest period available, using three-dimensional CAD data, present in stereo lithography (.STL) file format. Construction of the part or an assembly is usually done using 3D printing which is also known as additive manufacturing technology or Layer manufacturing. 3D printing technology has guided the technology in advancing the design and development more quickly and at a much lower cost than with that of the conventional methods. 3D printing has wide applications in research and development of components ranging from simple structures to complicated products. This paper presents an overview of rapid prototyping technology, its importance, classification and comparison of properties of products obtained by adopting some of the rapid prototyping techniques namely, Fused Deposition Modeling (FDM), Stereo Lithography Apparatus (SLA), Selective Laser Sintering (SLS) and other methods and the applications of rapid prototyping in various disciplines.*

Key Words: Rapid Prototyping, Fused Deposition Modeling, Stereo-Lithography Apparatus, Selective Laser Sintering, 3D Printing-Components, Applications.

1. INTRODUCTION

Rapid prototyping is an enabling technology for concurrent engineering. The basic design process of a rapid prototyping model includes- part geometry or 3D modeling (CAD file), data conversion and transmission or raw data (.STL file),checking and preparing, tessellation of CAD model, layer by layer build, post processing, validation of the part built. Rapid Prototyping works on different physical principles:

- Generation of component from Solid phase (Cutting, Binding, Sintering).
- Solidification of Liquid materials (Polymerization).
- Generation of part from Powder phase (Binding).

3D printing is very often used rapid prototyping method. It is a part of rapid prototyping method which uses the concept of 3D printing or additive manufacturing. 3D printing has the ability to fabricate geometrically complex shapes in a range of materials across different scales. It has various applications in medicine, art, manufacturing and engineering. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

ISO/ASTM52900-15 defines seven categories of AM processes: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photo polymerization.

2. OVERVIEW OF RAPID PROTOTYPING TECHNOLOGY

Prototypes were constructed by high skilled model makers from standardized 2 dimensional engineering drawing. The process was highly expensive and time consuming. With advancement in technology of new CAD/CAM technologies and layer manufacturing, prototypes are being produced rapidly from 3D CAD models. Rapid Prototyping method has two systems for two distinct markets.

- 3D Plotter design Office for generating components rapidly for visual verification and,
- Model making machine for generating functional parts and tools to high accuracy [1].

In rapid prototyping process, complete functional parts can easily be produced. Rapid prototyping process has two phases namely virtual phase and physical phase.

- Virtual Phase is for designing the required component using CAD software i.e., a 3D CAD is built in this phase.
- Physical Phase is for building the component. The 3D CAD model is sliced into thin layers and the part is built as per the sliced layers.

Thus, Rapid prototyping is thus known as Additive process and Layer based fabrication. The components may be represented as wire-frame models, surface models, and solid models [2].

Rapid prototyping is a generative manufacturing process. The prototype generation includes two fundamental process steps:

- Generation of Mathematical layer information.
- Generation of Physical layer model.

The generative principle of rapid prototyping methods paves a path in production of complex geometry. These processes are practically unlimited in the ability to fabricate intricate shape [3].

Rapid prototyping methods are being adopted to improve product development in three aspects:

- Design Engineering- Visual Verification and optimization of conceptual models in product design.
- Manufacturing- Prototype can be used for geometrical studies of the components at an earlier stage, which could speed up process planning and tooling design. Prototypes can be used as master patterns in castings.
- Marketing- Prototypes can be used to demonstrate the design ideas, concept, and company's capability to manufacture the part. Meeting customer needs and producing quality products in a timely manner is the key to penetrate into the market [4].

Thus, Rapid Prototyping methods became a hit with CAD users. As rapid prototyping processes vary from those processes used to make production part, it enables to fabricate a prototype which can be replicated in high volume production. The components can be fabricated quickly from CAD models without any fuss, as required by NC programming systems. CAD/CAM discipline is being headed up continuously by the adoption of rapid prototype technology [5].

3. CLASSIFICATION OF RAPID PROTOTYPING TECHNOLOGIES

Rapid Prototyping technologies are classified based on the initial form of its material i.e., the base material of prototype or part to be built. Thus, rapid prototyping technologies are classified into 3 categories.

3.1 Solid Based Rapid Prototyping System

Solid based rapid prototyping systems are meant to encompass all the forms of materials in solid state. The solid form can include the shape in the form of a wire, laminate, pellets or a roll. Solid-based rapid prototyping systems works on the following principles:

i. Cutting and Glueing / Joining method.
ii. Melting and Solidifying / Fusing method.

These processes are different from one another, though some of them use the laser in the process of fabricating prototypes. They all utilize solid in one form or the other, as the primary medium to create a prototype. Fig 1. Shows the 3D printed part of Oldham's coupling fabricated using FDM process.

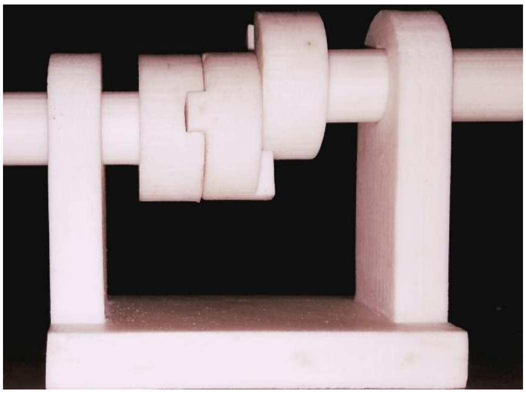

Fig -1: Solid Based RP System-Fused Deposition Modeling (Material-ABS Plastic)

3.2 Liquid Based Rapid Prototyping System

Liquid based rapid prototyping systems have the initial form of its material in liquid state. The base material can include a resin or a polymer. Liquid based rapid prototyping systems works on the principle of 'Photo curing' under which three methods are possible

i. Single laser beam method
ii. Masked lamp method
iii. Two laser beam method

Most of these systems build parts in a vat of photo-curable resin, an organic resin that solidifies under the exposure to laser radiation, in UV range. The laser cures the resin near the surface, forming a hardened layer. The formed layer is lowered by an elevation control system to allow the next layer of resin to be similarly formed over it. This continues until the entire part is completed. Under liquid based rapid Prototyping system, stereo lithography is very unique and patented process which combines CAD, CAM, CAE, Laser Scanning, Optical Scanning technologies including chemistry to fabricate 3D solid models from 3D CAD data [5]. Fig 2. Shows the 3D printed part of Oldham's coupling fabricated using SLA process.

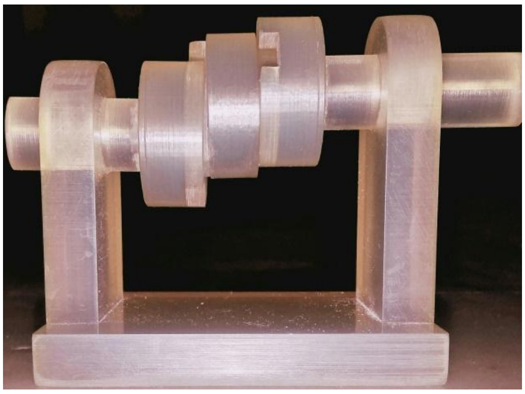

Fig -2: Liquid Based RP System-Stereo Lithography Apparatus (Material-Resin-Accura 60)

3.3 Powder Based Rapid Prototyping System

Powder particles are by-and-large to the particles of solid state in a strict context. However, intentionally it is categorized outside the solid-based rapid prototyping systems to refer powder in grain form. All the powder based rapid prototyping systems works on the principle of Joining/Binding. The method of joining / binding differs for all the systems, in that some employ a laser while others use a binder/glue to achieve the joining effect. Binder material is deposited on to selected regions of layer of powder particles to produce a layer of powder particles that are completely bonded at the selected regions. Iterations would fabricate the desired part. Post-processing is highly required to remove the unbonded powder particles [6]. Fig 3. Shows the 3D printed part of Oldham's coupling fabricated using SLS process.

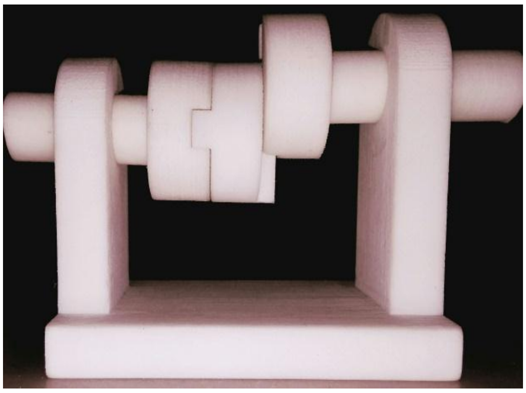

Fig -3: Powder Based RP System-Selective Laser Sintering (Material-Nylon PA-12)

4. COMPARISON AND SELECTION OF RAPID PROTOTYPING SYSTEMS

Optimization of an artefact for characterization of the form using the procedure of computed tomography (CT) with geometric dimensioning and tolerances and internal channels and the structures those are comparable to that of the cooling channels in heat exchangers. Investigation has been done to determine the accuracy and capability of computed tomography measurements and is compared with the reference measurements, determined by co-ordinate measuring machine (CMM).

The layer height for stereo lithography apparatus (SLA) and selective laser sintering (SLS) are same, but the layer height differs for fused deposition modeling (FDM). Thus, SLA and SLS can be compared like for like, whereas FDM has to be considered when comparing results [7].

Process parameters influence the accuracy of the part fabricated. Also the interactions of process parameters influence the dimensional accuracy of the fabricated component. Parameters such as raster width, path speed, slice height and tip dimension at two different levels must be taken into consideration to determine the influence of these process parameters and their interactions on the dimensional accuracy of the part fabricated. Rapid prototyping systems may involve large number of contradictory factors that majorly influence the accuracy during the fabrication of the component. A standardized methodology of optimization is used to determine the optimum level settings for the part fabrication. Thus, experimental and numerical analysis reveals that the control of the process parameters of the machine at appropriate levels, improve the dimensional accuracy of the fabricated component or part [8].

With the availability of growing number of rapid prototyping technologies and their capabilities, it has created a problem of selecting the appropriate method to suit the requirement. Thus, IRIS intelligent rapid prototyping system selector, an interactive program guides the potential purchaser to select the rapid prototyping system which suits the specific requirements. The program's database includes complete specifications of all systems. Thus, the program is used to compare specifications and applications of rapid prototyping system in making the final selection of the suitable method. The selection of appropriate rapid prototyping system can also be done on the basis of a quantitative analysis [9].

The selection of a suitable rapid prototyping process for the required application is facilitated by the parameters, orientation for building the component, building cost, manufacturing time, dimensional accuracy, and surface finish. The building cost is the primary optimization objective. Volumes of building inaccuracy, surface finish, manufacturing time are the secondary optimization objectives to resolve the tie-breaks for orientations, for building the model [10].

Part orientation for the part fabrication depends on the surface finish, support structure, shrinkage, build time, curing and part cost. A support system is developed to facilitate the selection of appropriate build direction as well as best suitable rapid prototyping process. The three major factors in determining best part orientation are the build time, surface roughness and part cost. A multi-criterion decision making method is taken into consideration in order to choose the best part orientation [11].

5. APPLICATIONS OF RAPID PROTOTYPING SYSTEMS AND 3D PRINTING

- Medical Applications: Rapid Prototyping is used to build solid replicas of all human organs and parts. Components like stretchers, broken limbs, prosthetics, etc., are majorly fabricated for bio-medical applications. The process involves the conversion of medical images to .STL files. The accuracy of reproduction of plastic models was notably superior [12].

- Design Applications: Parts fabricated by Rapid Prototyping method helps in design visualization, concept understanding and visual verification of the end part or the product.

- Engineering Applications: The Rapid prototyping systems helps in fabricating parts to required scales, to determine form and fit sizes, prototypes to perform flow analysis in various fields such as aerospace, automotive, bio-medical , ship-building industries. Due to various potential benefits in the rapid prototyping and 3D printing processes in membrane manufacturing, the use of the process of rapid prototyping in membrane engineering systems shows significant application [13].

- Aerospace And Automotive Applications: The rapid prototyping process has wide applications in aerospace and automotive fields; for design, visual verification, assembly, form, fit, limits, tolerances, clearances, inspection, testing, prosthetics, 3D casts, Metal casting etc.,

- Manufacturing Applications: Tools and parts such as moulds, castings-metal or sand, master pattern making using materials such as resins, rubbers, metals and ceramics etc., can be fabricated for their respective applications. Wind tunnel model components can be fabricated for its applications i.e., lightly loaded wind tunnel model components, also investment casting using rapid prototyping for pattern development offers strength and high production [14].

In addition to the above applications, rapid prototyping process shows its technological growth in textile industry, furniture design, electrical appliances, and architectural interior design and design of special and complicated contour objects [15].
Thus, the technology has been developing rapidly from past few decades, indicating a greater potential for further development and its applications in various disciplines. Also, the part fabricated from a technological concept, would develop valuable manufacturing trifecta along the traditional equivalent and subtractive manufacturing processes [16].

6. CONCLUSIONS

Rapid prototyping method accelerates the manufacturing field, reducing the manufacturing cost and lead times. Rapid prototyping systems offer opportunities to make the production faster at lower costs, with high dimensional accuracy influenced by machine parameters. The selection of appropriate rapid prototyping process depends upon the machine parameters, geometry of the part to be fabricated, its properties and the application of the part or product. This paper has reviewed rapid prototyping technology, its importance and applications in various disciplines.

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