Rapid Manufacturing: Classification and Recent Development

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Abstract—*Rapid Prototyping is an emerging technology in the field of advance manufacturing process/technique in which components/parts/models are rapidly created from the visual world (CAD model) to real world with minimum human interaction. Since the manufacturing starts with the creation of geometric data, either as a 3D solid using a CAD model, or 2D layers using a 3D scanning device therefore it is also referred as Layer Manufacturing, Material Deposition Manufacturing, Additive Manufacturing, Solid Freeform Manufacturing and Three-Dimensional Printing. This is one of the best techniques to manufacture prototypes which may be used for physical visualization, making some typical and intrinsic geometry. For the same requirement, in most of the cases it is very cost effective, flexible and time saving than any other available manufacturing technique. Therefore it is the most appropriate technique to manufacture or to recreate components/parts/model in different engineering viz. aerospace, product and tool development. A lot of new developments are occurring in the field of Rapid Prototyping Techniques in recent years.*

This paper also provides the development, trendsand applications of the Rapid Prototyping Techniques. The authors cover various available literatures to prepare concise and progressive review. There are various components which are associated with RP technique and some of them are listed in this paper.

Keywords— Classification of Rapid Prototyping, 3 Dimensional Printing, Poly-jet Printing, Rapid Prototyping; Sustainable Product Development.

I. INTRODUCTION

As the manufacturing field is one which converts raw material into finished/useful goods. The advancement in the field of science and technology make it versatile as new emerging technologiesare coming into existence. These changes forces the manufacturing industries to develop better quality of products in shorter period of time to have better market share in the competitive environment. Therefore it is required to evaluate all the feasible design alternatives which have least manufacturing cost and time constraints in order to obtain sustainable product development in the current era. The research shows that computer aided design; manufacturing tools and analysis technologies provides a very powerful resource tool for the futuristic designs. Further recent development in technologies like reverse engineering, rapid prototyping and rapid tooling etc. shows that these technologies provide very fast and less expensive ways to create parts directly from computer aided designed models(L. Kumar, Kumar, & Haleem, 2016).

In Rapid Prototyping (RP)technique, the physical model/prototype is quickly build directly from 3D CAD data. In totality, all the fabrication processes can be classified into three categories mainly, subtractive, additive, and compressive(Onuh & Yusuf, 1999). Every manufacturing process either falls completely into one of these categories, or combination of any of the mentioned process. In the subtractive process, the desired shape of material is carved out from a block of material with the help of tool whereas in additive process the desired shape/product is builds up by adding particles/layers of the raw material, and in the compressive process the forces are applied on semi-solid /liquid material to produce the desired shape and it is hardened/solidified if required. In RP processes the product is produce by addition of material layer-by-layer whereas in conventional methods this was done by removal of materials only.

In manufacturing field the productivity can be achieved by transforming product/object from raw material, as fast as possible with least cost and resource. Rapid prototyping can achieve this target effectively. RP techniques are capable of producing any complex geometries or internal cavities easily and efficiently. Also the cost, time, wastage etc. associated with RP is less as compared to conventional methods.

By using these technologies instead of conventional methods, the manufacturing time for producing parts with any complex geometry can be reduced to few hours as compared to days/weeks/months or we can say in other words, it is rapid. RP is an automatic manufacturing process and the basic concept of all RP process can be summarized into following steps:

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Step1. Firstly create a computer design (CAD) of the required model/design/prototype.
Step2. Then convert this CAD file into machine file format (.STL file format).
Step3. Slicing the STL (Stereolithography) file format into the required 2-D cross sectional layers.
Step4. Then growing 2-D design to produce required model/prototype
Step5. Post processing the model if required.
The RP cycle begins with the requirement of the desired product/model and end with the manufacturing of desired model/prototype however the whole cycle is repeated again and again till the required specifications are achieved and pictorial representation of the RP cycle/steps is shown in the Fig.1 below.

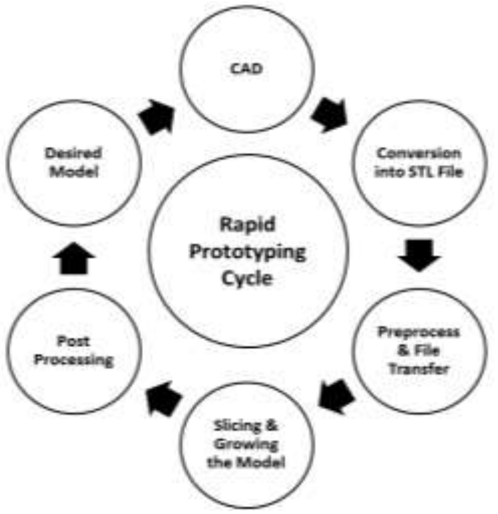

Fig.1:The RP Cycle from CAD design, repeated several times until desired characteristics are achieved.(Cooper, 2001)

II. HISTORY OF RAPID PROTOTYPING DEVELOPMENT

The history of RP techniques(Chee Kai Chua & Leong, 1997)is around two decades old as first RP system was developed in 1988. The development has gone through a number of changes which initially beginsfrom the introduction of mechanization in 1770. The one of the biggest milestone in the history was the introduction of first computer which was in 1946.The introduction of computers eventually speed up the growth process by reducing the process time. The manufacturing industry starts growing and developing when the computer was used along with numerical control in machine tool in 1952. The RP techniques can't be developed without the introduction of laser (1960) and robots (1961) for the manufacturing industries. The introduction of graphic system (CAD) in 1963 changes the whole approach of the manufacturing sector. The first RP system was introduced in 1988 by integrating all these systems to build model/prototype directly from CAD model without human interaction. The introduction of first RP machine initiated different RP systems along with it which are still under advancement by introduction of new and sophisticated control systems. The history of RP development(Chee Kai Chua & Leong, 1997)is given in the Table.1below:

Table.1: History of RP Development

1770	Mechanization
1946	Development of 1stcomputer
1952	Introduction of 1stNC (Numerical Control) machine tool
1960	Introduction of first commercial LASER
1961	Developed first commercial Robot
1963	First interactive graphics system (early version of Computer Aided Design)
1988	Development of 1st RP system (Stereolithography).

III. DIFFERENT TECHNIQUES OF RAPID PROTOTYPING

There are different RP processes developed in last few decades and some of them are discussed in this literature which are as follows:
1. SLA (Stereolithography)
2.Photo Masking or Solid Ground Curing technique
3. SLS (Selective Laser Sintering)
4.FDM (Fused Deposition Modeling)
5. LOM (Laminated Object Manufacturing)
6. 3DP (Three Dimensional Printing)

3.1 Stereolithography:

Patented in 1986 and this technique was invented by Charles Hull. A LASER is used in this technique togenerate ultraviolet (UV) beam which solidifies the uppermost layer of the photopolymer as per.STL file. The process continues layer by layer until the finished product is completed.The input to the machine/system is fed in the form of 3 dimensional CADmodel. The support structure is designed along with the final product in CAD model so that the structure is stable. The dimension of CAD model is such that the removal of bur is minimum. A translator is used to convert the drawing into .STL file.After successful loading, the control unitof the system,slice the drawing/model into numbers of layers with very small thickness. The automatic system (optical scanning system)is used to controls and focuses the UV beam on the surface of liquid (photopolymer) as per the program file to solidify the polymer. The platform moves/drops downwardwhich is equivalent to layer thickness after one layer get solidifyby UV rays and then second surface of the liquid get deposited on the previoussolidified layer. This process repeats layer by layer to build complete part/ product. Then the product is

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moved out from the machine tray and all the extra material/polymer is removed. Finally the post process curing is done to improve the physical properties like strength if required.

3.2 Solid Ground Curing

The Cubital Ltd. (Israel) proposed and commercially developed Solid Ground Curing method which is similar to SLA.The input data is generated by slicing three dimensional drawing (CAD model) according to the layer thickness. The production machine uses thisprocessed data file (.STL file) to produce entire product by curing a photopolymer layer by layer in controlled environment. The ultraviolet (UV) light is used to cure the material through a photo mask.In this technique post curing is not required.

From CAD file in the form of image of the layers are send to the mask plotter.The mask plotter produces image (basically a negative image) of the same layer with the help of a glass plate (which is charged with cations) and an electrostatic toner. During this time, the resin is spread on the work piece carriage. The resin loaded the work carriage and the mask plotter are kept together in sandwich mannerat the exposure area, where the shutter opens for small time interval (2-3 seconds)and expose the resin under UV light from transparent areas of mask plotter. After the exposure through transparent mask plotter, the exposed resin is completely cured and mask plotter returns back to its original position (plotting station). The wiper wipes out the uncured resin from the work piece. The mask plotter is then electrostatically erased and prepared fornext layer. Simultaneously in the same time, the part iskept under theUV light but without the plotter which solidifies the remaining resin that was not wiped out by the wiper. Thewhole carriage assembly is taken to the polymer/wax station, where a layer of wax is sprayed (which is very thin say 0.2 mm)on the work piece which fills all cavities and voids if present. The wax layer is then solidified with the help of a cooling plates present at the cold station.

The work piece assembly is taken to next station where the required thickness is cut down with the help of milling operation &the chips produced during this process are collected with the help of vacuum. The carriage is lower down as per the layer thickness and resin is spread for the next layer. The process continues in repetitive manner until the complete component is manufactured. The final prepared model is cured by dipping in hot water. In SGC process support structures are not required.Chipswhich are produced in this method are wastage and cannot be reused. This process can be used for geometric complex shapes with ease.

3.3 Selective Laser Sintering

Carl Deckard developed SLS in 1986 at Texas University (Austin). Selective layer sintering is aprocess that employs the use of powdered material approach to rapid prototyping. In this process a very thin layer (approximate 0.2mm depending on machine configuration) of hot powder (temperature just below melting point) is sprayed on the work table. A laser beam then moves on the surface area of hot powder in a specific pattern which is controlled by the source file (CAD file or .STL file).The heat generated by the lasers inters the powder together. This process continued layer by layer till the final component/product is produced. The unused/ un-sintered powder can be recycled/reused. The unused powder also acts like support for the work piece, so this process also removes the requirement of support structure. The materials which are used in this process include plastics, wax, metals, and coated ceramics.

However this method is different from the SLA. In SLA there is only one phase transition (from liquid to solid);whereas in the SLS there are two phase transition (first from solid to fluid & second form fluid to solid again).

3.4 Fused Deposition Modeling

FDM is also a RP technique which begins with software processing of CAD file (.STL file). Before starting the process, the selection of layer thickness and orientationof the component/prototype are mathematically done. The support structures are to be designed as per the requirements before starting the process. This machine can use a wide range of materials and colorsto process components so that different goals are achieved, say one color/material layer is used to manufacture one part of the prototype/model, another color/material for another part and another color/material for supporting the component/structure(L. Kumar, Tanveer, Kumar, Javaid, & Haleem, 2016).

In the beginning, of this process desired materials/thermoplastics are warmed up to a certain temperature (to glass transition temp.).This heated material is driven out in molten state with the help of an extrusion head. The extrusion head is been controlled by the tool-path defined by CAM software as per the instruction in the CAD file (.STL file). The part is manufactured from down to up, layer by layer. The raw material is provided in wire form, from the roller. The machine connected to the nozzle control the flow of the hot material(V. Kumar, Kumar, Haleem, & Rajesh, 2016).

3.5 Laminated Object Manufacturing

This process was invented by Helisys, Inc., Torrance; CA in 1989. The laminated object manufacturing is different from other systems. As in SLA, FDM& SLS the parts are building up by additive approach i.e. by stacking one layer over other through a forming process, but in LOM we use subtractive approach, i.e.the materials is fed in form of continues sheet which eventually make stake by cutting the desired shape through laser.

In LOM firstly, the sheets which are in winding bundles/ribbons are unwinds and then these ribbons are fed up to the machine with the help of motors through rollers. The rollers move the sheet over the work table and properly orient the material as per the machine platform. Sheet is placed on the work table of the machine. The sheet iscut according to the required shape with the help of a strong laser (CO_2 laser) beam. The unused sheet is wind on the other roller, in this process the new sheet comes over the cut section. A hot roller moves on the surface of the new sheet which binds the sheets together. The laser again cut the new sheet according to the new dimensions as per the .STL file. The process continues in repetitive manner. The laser beam is guided on the x-y positioning table with the help of sensors, mirrors and optics reflectors. Sometimes the unused sheet is not removed so that it can acts like support structure. After the completion of the process the stack of unused material is removed.

This technique/process is faster as compared to other techniques/process because the laser beam cuts the material on the periphery, which can produces a thick cross sectional layer in place of thin layers. Another advantage of LOM is that its part manufacturing ability is not limited by the complexity of the product/model which eventually leads to no internal stresses. The dimension accuracy is a problem.

3.6 Three Dimension Printing

The 3 dimensional printing is a process in which the three dimensional models/prototypes are manufactured directly from a computer drawing (CAD file). The 3DPprocess is very much same as that of a common laser/inkjet printer used in houses/offices. It works on the material addition approach in which different layers of material are buildup to produce the desired model. This techniqueused here is different from old manufacturing techniques in which products were produced mostly by removing the material. In this method the printing process begins with loading of required design file into .STL file format (from CAD file) in machine software. The machine deposits a layer of powder/liquid (as per machine specification) on the work table as per the instructions in .STL file. When the powder is used then the binder layer or laser (as per the machine specification) is used to join different layers. After the deposition of binder layer again a new layer of powder is spread on the work table. Since the binder is sprayed on the required area according to the dimensions, the new layer binds with the previous layer. If laser is used, the laser melts the powder on specified location which eventually binds with the previous layer.

Although there are numerous RP technologies available, they have some advantages and limitations. The selection of best technique depends upon many factors and however comparing all the available RP techniques one can easily find out the suitableprocess as per the requirement (V. Kumar, Kumar, & Haleem, 2016).

IV. COMPARISONS OF DIFFERENT RAPID PROTOTYPING TECHNIQUES

*Table 2:**Comparison of different RP techniques based on material used, energy required and wastage***(V. Kumar, Kumar, & Haleem, 2016)

Technique	Short Name	Materials Used	Energy Required	Fixture & Tool	Laser Used	Solid Waste	Liquid Waste	Aerosol Waste	Disposal/ Handling of Residues
Conventional Machining	CM	Iron, HSS, Al, metals & Alloys	Mechanical Energy	Required	Not Used	Tool scrap, Chips	Fluid mixture (Cutting cooling)	Tool particulate fluid vapors	By Landfill, recycling
Stereo lithography	SLA	Photosensitive Liquid (Photopolymer)	Energy of Laser (UV) beam	Not Required	Used	Resin & Supports	Non	Not Produced	By Burning, landfilling
Selective Laser Sintering	SLS	Polymer, Metals, Wax & Ceramics	Energy of laser beam (High power)	Not Required	Used	Chips of waste material	Non	Not Produced	By Burning, landfilling, recycling

Fused Deposition Modeling	FDM	Polymer, Ceramic, Wax &Alloy	Only Heat Energy	Not Required	Not Used	Chips &Supports	Non	Not Produced	By Burning, landfilling, recycling
Laser Engineered Net Shape	LENS	Metals & binders	Energy of laser beam (High Power)	Not Required	Used	Material Chips	Non	Not Produced	By Burning, landfilling, recycling
Laminated Object Manufacturing	LOM	Paper, Polymers, Metals & Ceramic	Energy of laser beam (High Power) &Heat	Not Required	Used	Material Chips	Non	Not Produced	By Burning, landfilling, recycling
Inkjet printing	IJP	Liquid Material Inks	Energy of Piezoelectric nozzle	Not Required	Not Used	Microchip & Supports	Non	Not Produced	By Burning, landfilling, recycling
Three Dimensional Printing	3DP	Metals, Ceramics & Binders	Energy of Piezoelectric nozzle &Heat	Not Required	Not Used	Supports& Chips	Non	Not Produced	By Burning, landfilling, recycling

V. RECENT DEVELOPMENTS IN THE FIELD OF RAPID PROTOTYPING

The RP is a very new and emerging technique which is developing day by day. However there is lots of work which required to be done in this field and as per the available literature the development of RP can be summarized into six basic categories namely(1) Basic fundamental about RP Technique (2) Selection from different RP techniques **(**3) Product development/design using RP (4) Optimization of RP machine(5) New material development in RP (6) Impact of RP. The development about RP is discussed in these sections and these are discussed one by one in the coming sections described below:

5.1 Basic fundamental about RP Technique:

Poly Jet 3Dimensional printing is a technique which is similar to laser/inkjet printing of documents. The difference between two is that in place of printing/ink jetting the liquid drop on the paper as in conventional printing, here we build the liquid layer of photopolymers/powder on build tray which can move and cure the printed material under ultra violet or laser light(Javaid, Kumar, Haleem, & Kumar, 2015). And then after curing is done for one layer we move the tray by layer thickness and whole process repeats and goes on increasing to produce final 3D mode/prototype. Finally curing of model is done if required. The basic idea of almost all the RP techniques is similar and a brief overview about RP can be addressed from the following papers/authors.

(Tu, Xie, & Kam, 2006) presents main objectives of rapid OKP development for the global manufacturing industries environment and also reviewed the background for rapid development of products. The issues such as continual customer influence, product data complications, flaws related to information, complications of logistics management, very high customization, fatter/looser production planning and control etc. are discussed. And the requirement (Enterprise integration, Support cooperation and collaboration, Stability and easiness in use and maintain etc.) needed for developing of a new production system (new generation)which can produce product rapidly was purposed. A reference system was also developed for easy comparison and understanding. The suggested reference system was open structure and it is internetbased on the process of development of the products rapidly.

(Onuh & Yusuf, 1999) provides an overview about the growths and trend of the technology, areas of applications and significant benefits of RP technology to manufacturing industries. The study covers process fundamental and also deal with the issues related to (1) the stair-stepping phenomenon (2) Selection of layer thickness (3) Deviation of actual geometry from CAD model (4) Issue related to orientation of parts (5) The use of support structures. Process flow chart and application of RP technology is also discussed in brief.

(C K Chua, Hong, & Ho, 1999) discussed various popular rapid tooling techniques and classified them as hard or soft tooling (also direct or indirect tooling). The comparison of different techniques was also addressed based on the factors as tool life, development time of tool and the cost related to the development of tool.

5.2 Benchmarking/Selection of RP techniques

Different RP technologies have different advantages and limitations and the selection between these techniques depends upon the need of manufacturer. Depending upon the requirements and benefits of the manufacturer can compare all the RP techniques and select best among them. However for most suitable technique the comparison should be done carefully by considering all the factors/points. For selection among different techniques available on RP one can go through these papers which present very good comparison based on different requirements/questionnaires to choose best machines which suit as per requirement.

(Way, Zu Hazmin, Zainal, & Zahir, 2009)presents a QFD based benchmarking technique to compare and to select the best RP machine for different purpose (academic as well as educational) in Malaysia. Their research consider 17 aspects as customer requirements (Demanded Quality) and 17 aspects of functional requirements (technical measures of quality) and competitive analysis them for 5 different RP techniques. Among these five techniques (FDM, 3DP, LOM, SLS, SLA) the result shows that 3DP machine is best for educational purpose based on fact of machine cost, machine maintenance cost, reliable to produce complex design, raw material cost and another important aspects. However one of the limitations of their QFD approach is that it cannot take into account the uncertainty and ambiguity inherent in the assessment of customer requirements.

(Brown & Stier, 2002) presents different questionnaire for selecting RP system for first time purchaser. Their work covers different questionnaire based upon (1) Hardware, software and contractual questions (2) Faculty related questions (3) Industry type questions (4) Prototype related questions (5) Facilities and machine supervision questions and also suggested comparison chart for different machines. These questionnaires help in selecting the current type of RP technology or in purchasing the RP technology for the 1sttime. The question of purchasing and selection is very hard to answer accurately as it depends upon many factors but yet they provided many details and included many issues which tries in providing optimum solution to the problem.

5.3 Product development/design using RP

The RP has the ability to quickly produce real working prototypes. These models can be usedin many ways such as tounderstand how a design looks, feels and operates.It also gives us better and fast result to develop new product/component or to modify existing model. For development of new design or product RP is best techniques. (Ilmars & Natalija, 2011)discusses the new product development stages (development phase to production phase), and the innovative development result infunctional prototype RP method. They analyze the benefits of using RP in new product development and make a comparison (based on different raw materials) between different RP systems which are available and can be used for innovative product development. The suggested stages consists of, development of product from its idea, making the 3 dimensional drawing/model of the idea, analyzing different parts of the model, rapid prototyping the model, and then post treatment if required.

(Xie & Tu, 2006) presented a computer based RP system which can work on internet or intra net based systems. The suggested system consists of many computers which are interlink through intra/internet and every computer function like a subsystem for the main system for fast working. The system works on product development method/strategy which is known as "prototype based incremental product development strategy." The system has product production data structure for database management which is actually a management software tool used for rapid development of intra/internet based product development systems. The industrial implementation is also listed in the paper with database management structure and product development method/strategy. The proposed work decreases the product development time in companies switched in New Zealand (SMOKP companies).

(Ilyas, 2013) provides an aspect that how to combine the machine vision (3Dimensional MV) with rapid prototyping. The proposed system based on reverse engineering which simplify and groups the main system into 3 main sub system/phases. First is the scanning phase, second the processing and modeling phase, and third is verifying the model. The suggested process was integrated with Fused Deposition Modeling (FDM) for rapidly development of prototyping for design. Implementation procedures at POLMAN Bandung, was also overviewed by the authors and for better understanding the problem the also provides some examples.

5.4 Optimization of RP machine

The optimization of different techniques is very much necessary as to remove unwanted time and resource which are of no use. The optimization work done by different authorscan be summarized in the Table.3described below.

Table.3: Optimization of RP machines

Sr. No.	Year	Authors	Area of Work/Research	Finding
1.	2000	(Allen & Sachs, 2000).	• Worked on the fabrication of metal tooling parts for molding plastic tools. • Worked on tool steel powder and bronze infiltrates • Infiltrates are used which contain depressant (fast diffusers) to reduce meltingpoint.	• Obtained improved mechanical properties • Improved the macro hardness • Surface finish was improved with accuratedimensions also wear resistivity and product complexity improved.

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2.	2008	(Kumbhar, Pandey, & Rao, 2008)	• Presented a curve model which was based on Intermediate point curve method(IPCM). • The reverse engineering was combined with rapid prototype technique. • Improve the process by removing the process of validation/repair of .STL file.	• As the .STL file was improved it removes the errors arising due to best fitting of surfaceand its triangulations. • Proposed system was verified/ tested on both simple and complex objects. • Its limitation is that this approach cannot handle the objects itself.
3.	2010	(Ollison & Berisso, 2010)	• Determine the effects of building orientation, printing head & its life along with the diameter of the 3D printed part on their cylinder city • An analysis of variance (ANOVA) study was conducted	• The results of this study suggest that the building orientation was the only one parameter which had a significant effect on the cylinder city of 3D printed parts
4.	2011	(Udroiu & Nedelcu, 2011)	• This research was performed under the innovative platform developed for inter disciplinary Technical Development. • They optimized the data input software. • Compared the surface quality (surface roughness) for inkjet printing and polymer jetting printing • Work was focused on fitting of different parts on the building tray with considering all previous points.	• The part orientation was optimized on the build tray basedon minimization of time of building and support structureswiththe criteria of better surface quality. • The result shows that the quality of components /partsmanufacturedwith poly jet printing technology was very good and also they did not required any post processing • Whereas the components /parts manufactured byZ Printer have lowest precision and were very fragile (require post processing).

5.5 New material development in RP

The RP is one of the philosophies which can use almost all the materials (Polymers, wax, cement, wood, metals, ceramics, nylon, glass, alloys etc.) to convert them into finished goods. For the development of new material that can be used in RP machine various observations or finding are discussed in Table.4below.

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Table.4: ***New material development in RP***

Sr. No.	Year	Authors	Material (Study/Used) / Outcome
1	2006	(Prashant, Senthilkumaran, Pandey, & Rao, 2006).	• Polymers, ceramics/cermet, wax, composites nylon/glass composite,alloys, metal-polymer powders and metals. • Research covers the issues related to processing of bio-materials and functionally graded material (FGM) for bio –medical applications.
2	2006	(Makoto et al., 2006).	• Works on the formulation of novel hot melt inks. • Inks have been modified with particular chemical substances, blowing agents, in order to obtain raised images on a substrate. • The novel hot melt ink consists of different waxes(Carnauba/PE wax alloy), tackifier (Hydrogenated rosin ester) and plasticizer resins (Polyamide), rheology modifiers, and gas releasing agents. • The blowing agents (sodium bicarbonate; p-toluene sulfonylhydrazide; azodicarbonamide (ADC); and p, p-oxy-bis(benzenesulfonylhydrazide)) present in the ink decompose right after the ink deposition and form gas bubbles, which are entrapped in the solidifying ink droplets.
3	2008	(Utela, Storti, Anderson, & Ganter, 2008)	• Presented the steps involved in process development for new material system in 3 DP which makes the material flexibility in 3DP. The numbers of steps involved are • 1st Formulation of the new powder, • 2nd Selection of thenecessary binding method, • 3rd Formulation of the new liquid binder and testing its suitabilityand interaction with printed powder, • 4th Specification for the printprocess's parameters, and • 5th Specification for the post-processing techniques/procedures
4	2011	(Williams, Cochran, & Rosen, 2011)	• Additive manufacturing process based on layer printing for metallic cellular materials. • Cellular ceramic green components/parts are fabricated by selectively printing the metal oxide which is very fine powders (the powder is spraydried along with a binder to increase granules formation for the processing) with a 3 Dimensional Printing machine. • The part is then sintered (3 stage sintering) in a reducing atmosphere (10% H2) to convert it into metal chemically. • The resultant metal is maraging steel (Fe, 18.5Ni, 8.5Co, 5Mo) obtained by converting metal oxide. • It creates cellular artifacts and can also be used to produce walls (thickness up to 270µm), channels (up to 1.1mm diameter), and angled trusses (up to 1mm diameter). • The process can produce final/finished parts which have relative density on 63% and shrinkage (linear) of 45 %.
5	2011	(Gill & Kaplas, 2011).	• Compared the efficiency of two 3 Dimensional powder based technologies (Z Cast process and investment casting) for casting of light

			aluminum alloys (A356) and zinc alloy (ZA-12) • In Z casting process, Z Cast 501 powder was used to print split pattern with sand support for aluminum alloy. • Investment casting of starchbased zinc alloy (ZP14) powder and plaster based (ZP100) powder were infiltrated (acrylate and wax) to make pattern.
6	2011	(Castilho, Pires, Gouveia, & Rodrigues, 2011).	• Worked on 3 Dimensional printing for bone repair. • Prepared tissueengineered scaffold for bone repairingwhich have very tight distribution of pore sizeand good controlled geometries.
7	2013	(Maleksaeed i et al., 2013).	• Use of Inkjet 3D printer to print titanium scaffolds bone parts with customized pores and part geometry. • To make titanium printable, its power (titanium powder) with spherical shaped particles with suitable sizewas prepared • The ball mill/mixer or vibratory mill/mixer is used for powder making and then the powder is dried mixed with a polymer (PVA) which is water soluble. • Titanium it is a biocompatible metal asit is biologically inactive and also it does not produce any undesirable effect on growing cells in the implant. • With suitable/optimum process selection we can produce porous titanium bodyparts which have similar mechanical properties as that of bone.

5.6 Impact of RP

Without considering the impact of any technique we cannot conclude whether the technique is useful or not. So the performance evaluation of RP based on its impact on environment, human, economy, society is been discussed here and the impact of various factors can be summarized as:

5.6.1 Environmental Performance

(Luo, Leu, & Ji, 1999)present a method based on environment friendliness which comparesdifferent rapid prototyping (RP) and rapid tooling (RT) process. Their work was based on the assessment of environmental performance for RP and RT process and the result was based upon the environmental indexes which utilize the eco indicators to measure the performance. Each of these processes was divided into four numbers of life stages namely, 1stmaterial preparation2ndpart build 3rd part use and 4thpart disposal. And then the impact/performance based on environment friendliness of each stage was evaluated firstly by identifying stage wise environmental impact factors and then summing all these values to calculate total impact. The assessment method considers material use, energy consumption, process waste and disposal of part after normal life at different stages for evaluation also their work covers an example to illustrate this assessment method applied on one stereo lithography process and two rapid tooling processes.

5.6.2 Economic Analysis

(Wittbrodt et al., 2013) presented a study to evaluate the economic selection between rapid prototyping technique and conventional method. This research was based on the printing of 20 designs which are used in common household. These design are freely available on the open internet source and these are the common household items which can be printed through Rep Rap technology in United States of America. The economic analysis was based on the cost and time taken to produce these items through RP and then result was compared with other methods (low/high market price, internet sources) to have these products. The analysis includes the printing time taken, filament consumed rate and other costs in printing. The result of the analysis shows that by using RP there is saving in cost range from \$300 to \$2000/year and it provides a payback time of 0.3 to 2 years with rate of return 40% to 200%. However the analysis do not covers all the variables which can also affect the result financial like energy cost, primary capital cost, discounts, inflations, loan charges etc.

5.6.3 Mechanical Noise

(Cohen et al., 2011) presented a study to measure/calculate the mechanical noise produced in tissue printing.The mechanical noise/temporal variation produced during tissue printing using hydrogel as printing material was measured and the effect of mixing different homogeneity of alginate hydrogels was studied. The result suggest that for reduction of mechanical noise up to 82% can be achieved using proper mixing (up to 128 cycles) between alginate and cross linkers. The smoothness in surface texture shows the improvement in geometrical fidelity with better target matching and very less point defects. The mixing also shows positive effect on cell viability which was improved by 34 % with curing time of 45 min. The result also shows a rise in modulus strength by 110 % that was 4 kPa before and 8.4 kPa after increasing the mixing cycle to 200 cycles from 8 cycles.

5.6.4 Societal Impact

(Huang, Liu, Mokasdar, & Hou, 2013)compares the additive manufacturing (AM) processes with conventional manufacturing based on their societal impact. This study covers the impact of additive manufacturing on human health, along with its impact on manufacturing supply chain. The environmental effects of chemicals which are used in AM processes is studied, & their potential health and occupational hazards, energy consumption and environmental impact is also considered. However the limitations of this study shows that the health factor of all the AM materials used,was not established and also it required more research to accurately evaluate various AM processes.

5.6.5 Structural Strength

(Le et al., 2012)studied the hardened properties of printed concrete. The concrete was printed through extrusion with a 9 mm diameter nozzle.The concrete was a fiber reinforced to improve its performance andmade up of fineaggregate through layer by layer process printing process (3 D Printing). Different mix proportions were made and their effect on different properties of concrete (strength compressive, tensile and flexural, % shrinkage when dry, and density) was studied with different printing layers orientations. The result obtained shows that a well printed concrete can havea density of 2350 kg/m^3, compressive strength of 75–102 MPa, flexural strength of 6–17 MPa. However these results depend on the testing process and direction. The voids (porosity) depends upon the printing process can vary from 4.8% (poor printing) to 1% (good printing) whereas it was 3.8% for mold casting process. However further research is needed to verify/assess the behavior of the printed concrete under actual working/service conditions also to find the effect of different layers on durability of the structure.

VI. APPLICATIONS, ADVANTAGES AND DISADVANTAGES

6.1 Applications of RP:

The RP technique is an optimum method to produce any product and it has wide range of applications. Even if this technique is still under development it can be effectively applied almost everywhere and for any shape and any material. Some of the typical applications of RP include reverse engineering, rapid tooling, casting, modelling, and product development. It finds its immense applications in the medical field like custom fit mask, new organ development, operation practice etc. It is also used in fine art and jewelry design for fast and custom fitted designs. It is also used in forensic science and ancient monument redesign and study. Most recent development and study shows that RP is also being used for making houses, automobile parts, aircraft parts etc. Thus this technique has lots of potential which have to be utilized.

6.2 Advantages of RP:

This technique offers a number of advantages. Studies show that application of RP in the industries drastically reduces both cost and time. It saves lots of resource, time and money in the process of new product development.Burns M(Burns, 1993)suggest that companies are trying to utilize this technique in more innovative ways than others.The use of RP increases the complexity in shape and size of the product. An added advantage of this technique is that, unlike subtractive manufacturing, it does not leave unused cut-off stock or chippings.Since the corrections in the product are made early in the process stage so it saves time during product development stage.

6.3 Disadvantages of RP

The RP technology is an emerging technology which is still in its development phase and requires a lot of thought and development. Despite of recent the advancements in this field, there are numerous limitations associated with it. One of the biggest limitations is the cost factor which limits its application in small scale. Traditional manufacturing process is usually much faster and less costly when mass producing identical parts. Another limitation is the lack of flexibility in the materials which can be used in the RP machine. Since it lacks sophisticated control and laser systems, controlling the surface finish and precise dimensional accuracy is somewhat challenging which requires lots of work to eliminate the gap. However with the incorporation of new and better techniques these limitations will cease to exist. Further for its rapid growth, awareness about this technique and concurrent research is needed. However a complete shift of the paradigm from conventional techniques to RP technique is not an easy task and requires time to gain the confidence and to overcome the fear among the people about the shift. Some of the main disadvantages of rapid prototyping are as follow:

- Traditional manufacturing process is usually much faster when mass producing identical parts.
- Per piece cost can be high, base material expensive, no economy of scale.
- Most have poor surface quality.

- No quite as strong, often more brittle.
- Material options are limited.

VII. CONCLUSION

This paper covers an overview about the different rapid prototyping techniques (Fused deposition modelling, Stereo lithography, 3D printing, Selective laser sintering, Laminated object manufacturing). The RP is a new and emergent technology in which models/prototypes are produced directly from CAD into desired shape by additive process (in layer by layer). In this paper the classification and comparison of these different techniques/processes based on different factors is been done. Also the advantages, limitations, performance, and applications of RP techniques/processes are addressed in this paper. It covers the history and development of different RP technique based on various available literatures. It tries to address how to select best technique from different RP techniques based on manufacturers requirements/questionnaires and the problem of benchmarking product development and new material development has been addressed and then the optimization with performance evaluation of RP techniques/processes is also been done.

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