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Review Article

TRENDS IN THE DOMAIN OF RAPID ROTOTYPING: A REVIEW

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RP answers the need of green manufacturing which is the need of hour in the manufacturing sector. A large number of commercially viable RP techniques are available in the market today. This paper attempts to introduce and review the newer RP technologies. It summarizes the applications of different commercial RP technologies available. It finally recognizes the current challenges in this field and suggests probable solutions based on extensive literature survey.

Keywords: RP, SLS, SLA, 3DP, SDM, LENS, FDM, RP classification, RP applications

INTRODUCTION

In product design, prototyping is an imperative final step. Prototyping requires design, fabrication and testing of final product design. This practice started with manual prototyping then extended to prototyping with soft curves and presently prototyping is done with the aid of computers and is called rapid prototyping. RP/LM is accomplished by layer-on-layer material deposition. This started during early 1980s with massive improvement in CAD/CAM technologies.

The current trend is the direct manufacturing of physical objects starting from 3D CAD models without any classical tools. This is termed rapid prototyping, solid freeform fabrication, layered manufacturing, green manufacturing which are different names for this automatic prototyping (Debasish Dutta *et al*., 2001). Advent of RP is a watershed event similar to advent of CNC tools almost 3 decades ago (John Michael Brock *et al*., 2012).This marks an era of introduction of flexible automation. This process tremendously reduces the design cycle time especially for intricate and complicated jobs.

Despite this tremendous growth in this field, there are numerous challenges to be dealt in this field. While outlining the problems in RP applications; this paper also highlights the applications.

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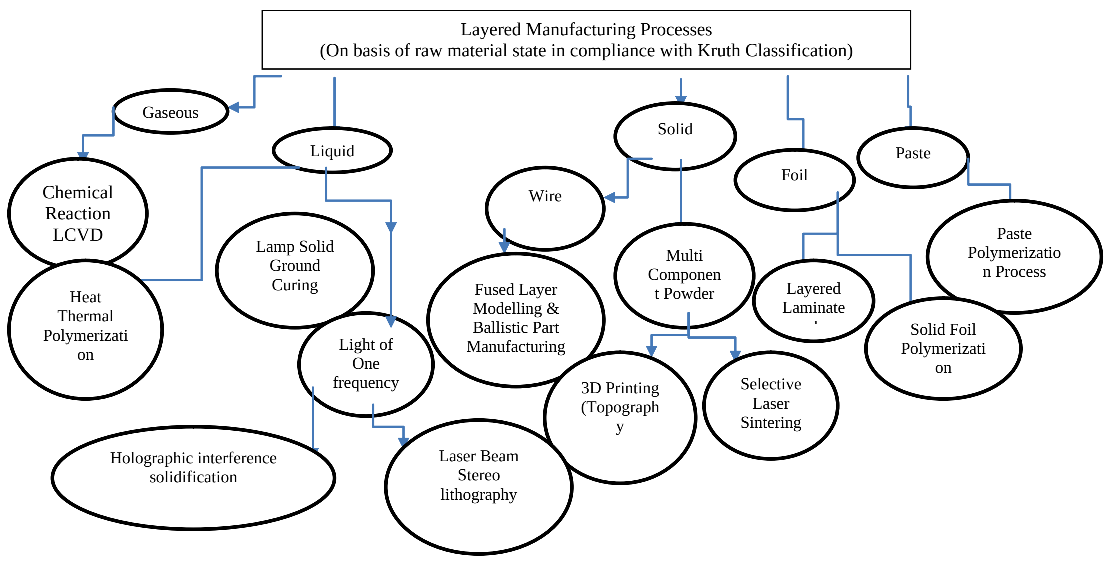
WORKING STEPS REQUIREMENTS

1. Geometric modeling
2. Data transfer and CAD interface
3. Slicing
4. Merging
5. Building the model
6. Starting the machine
7. Final post curing and finishing works

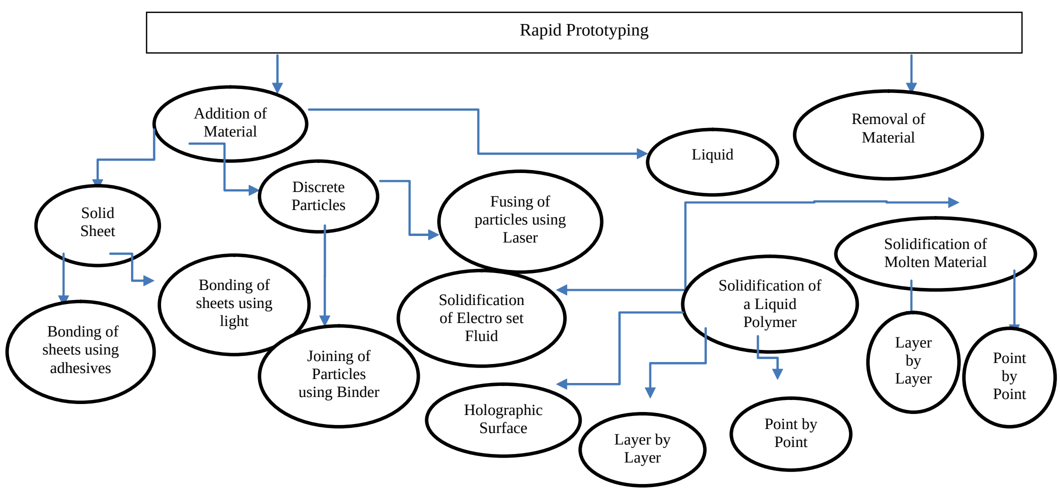
CONVENTIONAL CLASSIFICATION

Figure 1: Conventional Classification of RP Processes



An alternative approach to classification is suggested by D.T. Pham, R.S. Gault

Figure 2: Alternative Classification of RP Processes

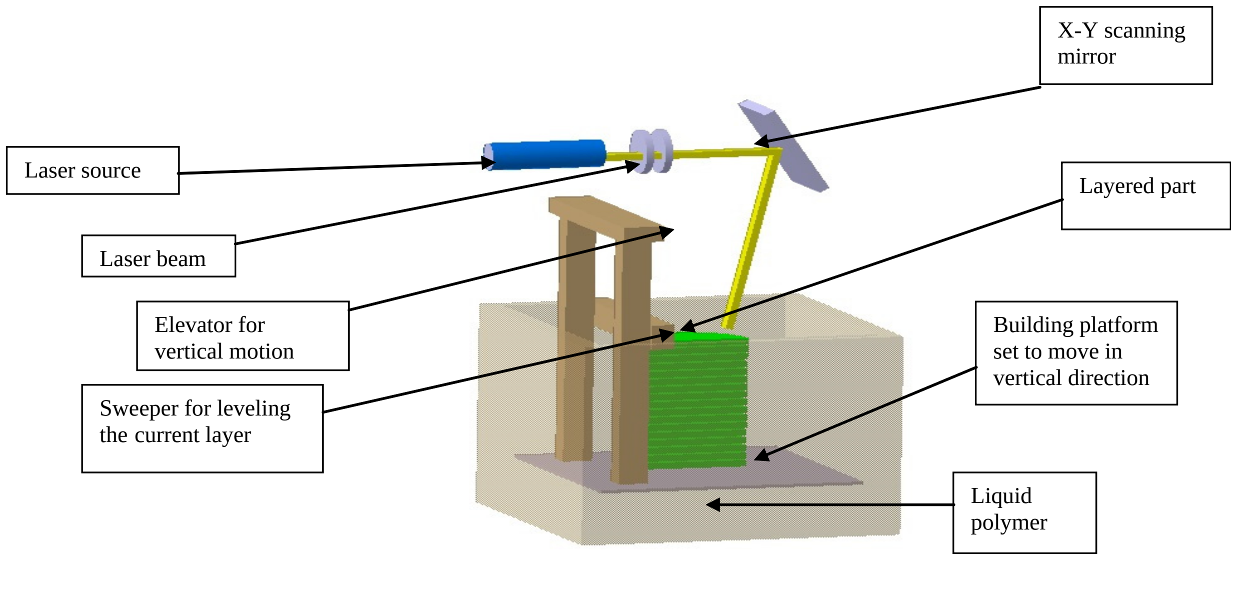


RAPID PROTOTYPING TECHNIQUES

Stereo Lithography

It is a rapid prototyping technique that involves photo polymerization that draws or prints on a photo curable resin, the cross section of a model. This is a recent technique that attracted much attention because of its ability to make wide range of products with high accuracy. However, the dimensional accuracy produced is not better than conventional machining processes (H S Cho *et al*., 2000). SLA fabricates parts without intermediate tooling, directly from a CAD model, in the opposite direction to gravity. Support structure is required to hold the stacked layer and resin during the fabrication process. The stair -stepping effect occurs by staking layers when fabrication on an inclined surface (Ho-Chan Kima and Seok-Hee Lee, 2005).

Figure 3: Stereo Lithography Apparatus



Selective Laser Sintering

A freeform, additive manufacturing process that uses laser on power beds to create 3-D models. Its starting point is a 3-D CAD model of part geometry out of which 2-D stack of layers are derived which represent the part. A laser spot is created by scanning over the cross sectional area to create each layer, which results in sintering, melting and bonding particles in a lamina. The same process is repeated so that entire stack of 2-D layers is created and bonding takes place to form the original 3-D CAD solid model (E O Olakanmi, 2013).

Electron Beam Melting

It is an additive manufacturing process, which forms a 3D object based on a computer model by utilizing an electron beam to melt alloyed metal powder layer by layer. This technique unlike conventional techniques, anticipates microstructure and properties of EBM produced material. It is emerging as a method for production of orthopedic devices with various material, including Co-Cr-Mo Alloy (R S Kircher *et al*., 2009).The parts are build up in a vacuum chamber. Later the parts are cleaned by conventional techniques

Figure 4: SLS Machine Setup

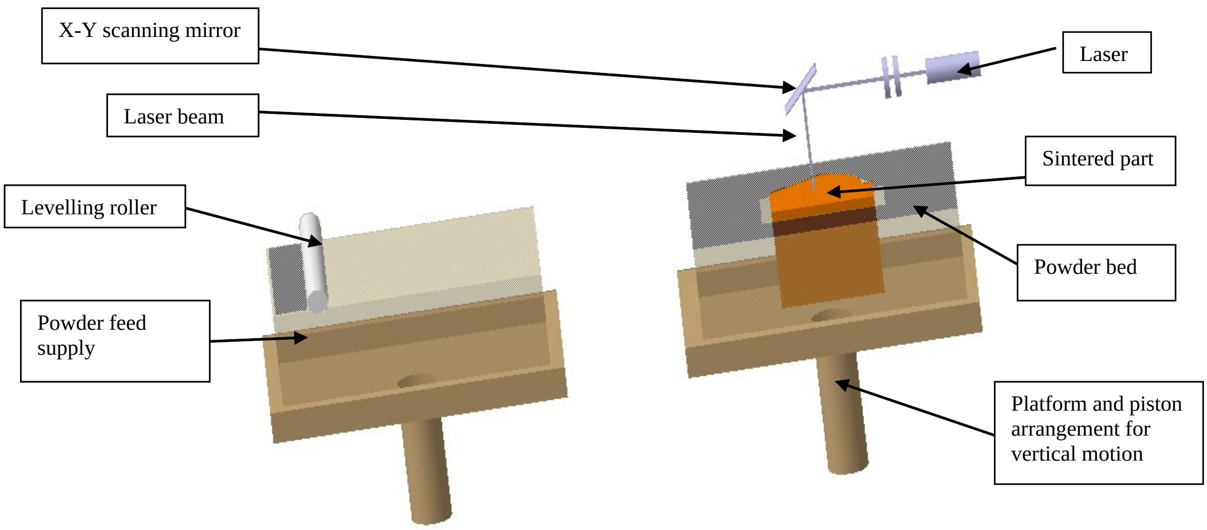


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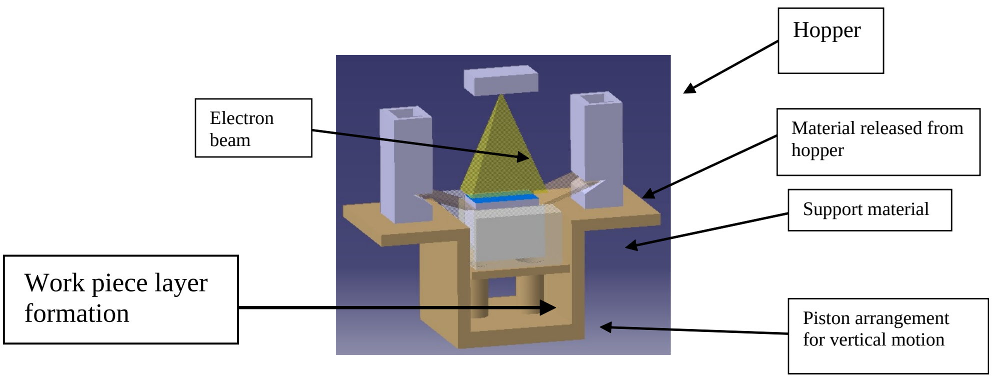
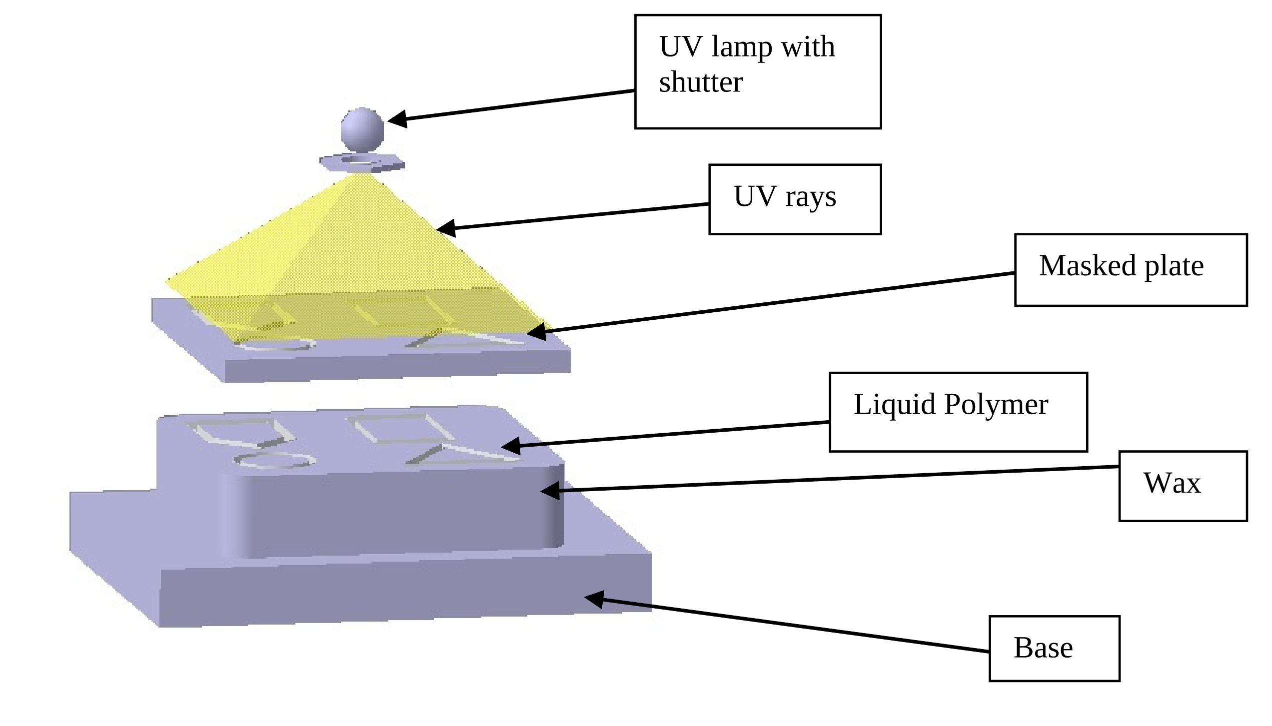
Figure 5: Electron Beam Melting Setup



Solid Ground Curing

It is a process is suitable for building parts in batch, with different dimensions and geometry. Although problems like quality, material properties and accuracy limit the application of the prototypes. However the method offers very high fabrication rate with adequate accuracy, complexities lie high accusation rate and operating cost are the biggest hurdles.

Figure 6: Solid Ground Curing Process



Laser Stereo Lithography

A wide variety of material can be processed by high power laser. It uses ultraviolet laser as a source when applied to organic compounds in a conventional process. In the traditional approach the process of fabrication and development of models allow curing of part by exposing to UV light, leading to formation of 3D object.

Holographic Interference Solidification

The entire surface is solidified by exposing the resin to holographic image. The image is obtained from the CAD model but not in terms of slices. It also has still not been commercialized.

Laser Engineered Net Shaping

It is a freeform fabrication process. It involves fully dense 3D shapes from laser processing of ?ne powders, directly from a design model. The LENS process makes near net shaped complex prototypes, leading to reduction in machining and time cost. The LENS process can be used to deposit a variety of metals and alloys, such as 316 stainless steel, titanium alloys and H13 steel nickel-base super alloys (J N DuPont, 2003).

Figure 7: Lens Setup

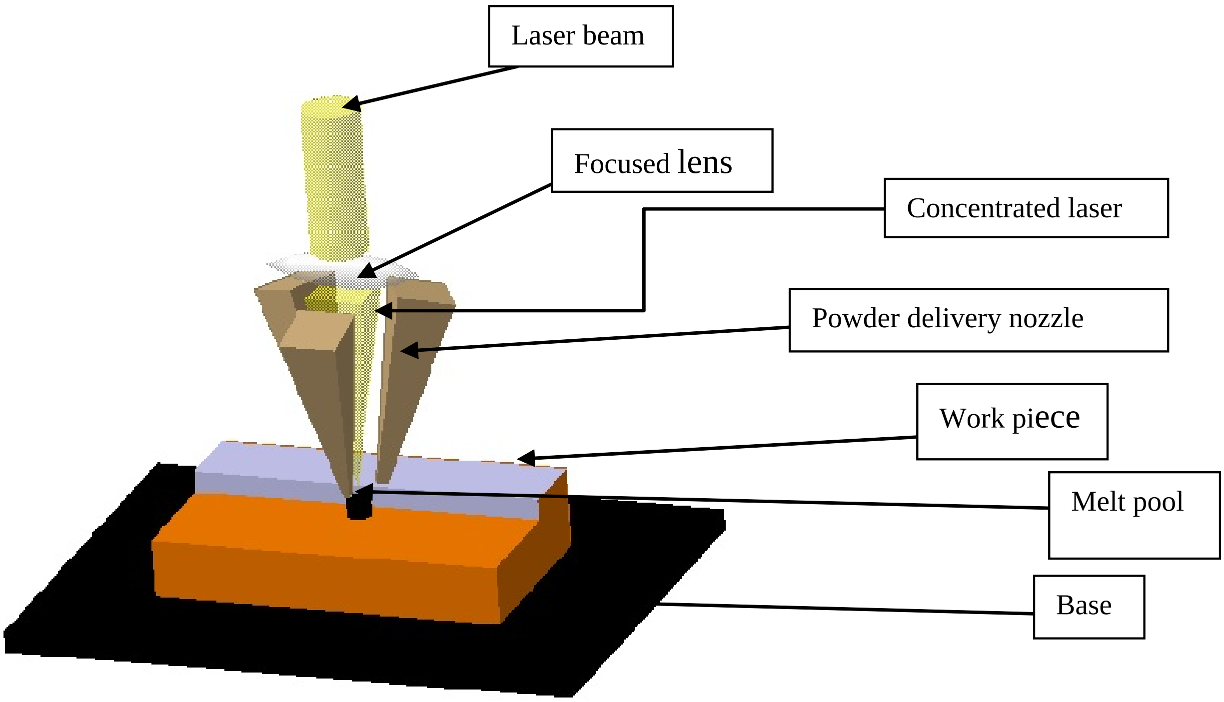
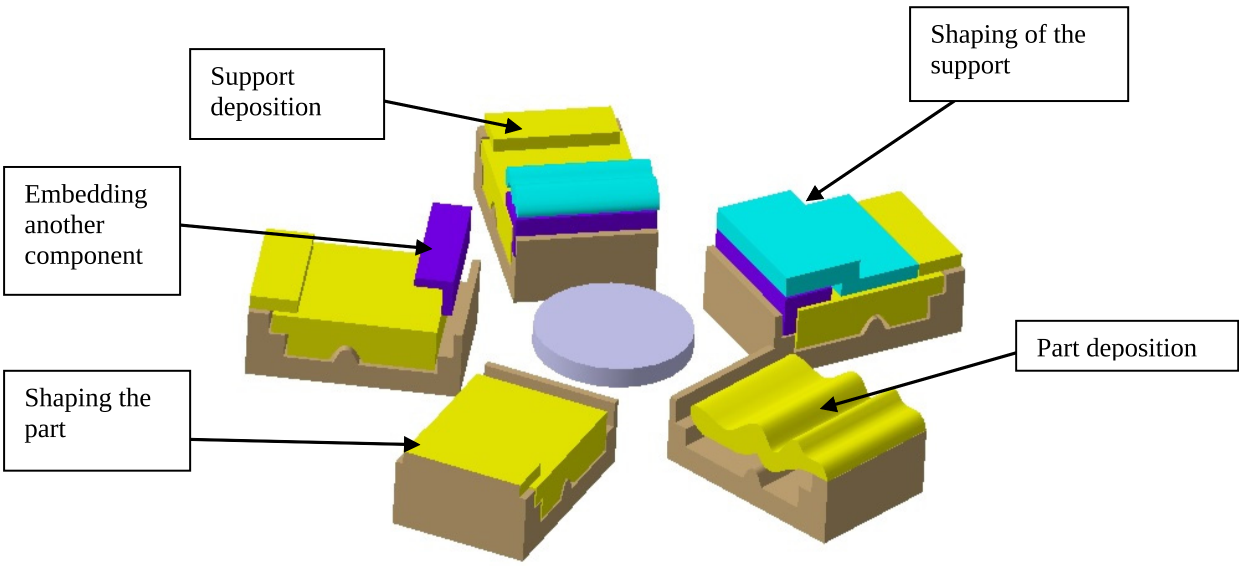


Figure 8: Shape Deposition Modelling



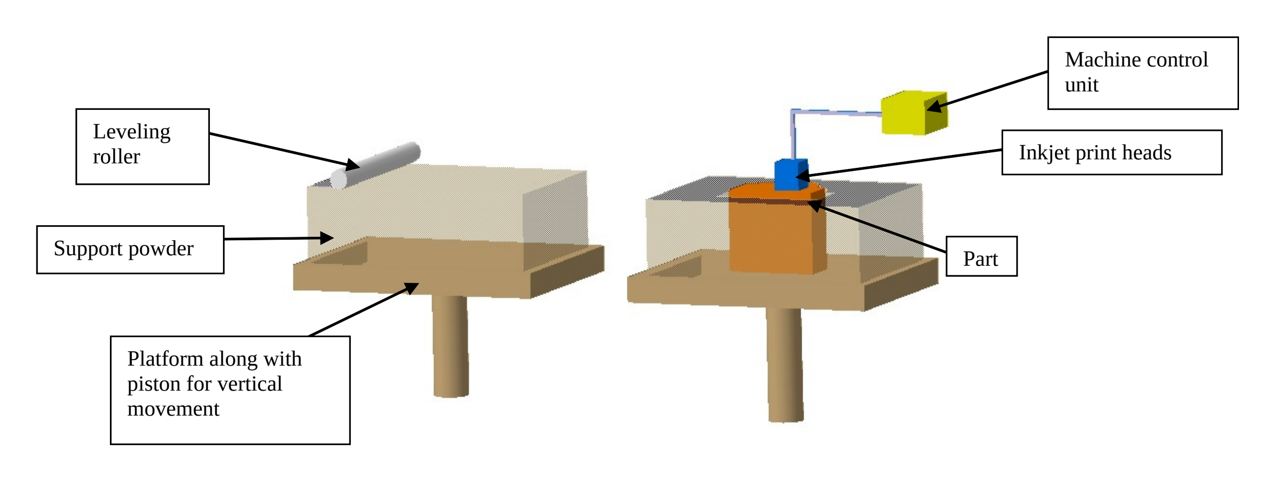
Shape Deposition Modelling

It creates metal parts with incremental deposition of metal and removal of material as well. It adds the benefits of SFF and CNC. It produces parts with poor surface quality. The non-horizontal and vertical surfaces exhibit stair step effect. The mechanical properties are critical to layer boundaries which are a potential source of defect. To solve these problems mold SDM was developed which can build complex shaped parts. However, it uses CNC milling to shape the surfaces effected by stair step effect. Since the product is monolithic so no boundary layers are there I end product, this is in spite of the fact that the mold is built in layers (A G Cooper *et al*., 1999).

Three Dimensional Printing

It involves the creation of 3D object by depositing powder with the help of a liquid binder. It is a very versatile process which can make variety of complex models with different kinds of material. They have very low cost, high speed and wide application

Figure 9: 3D Printing



Electro Setting

Conductive Material like aluminum is used. After printing of all the layers, stacking is done and they are then immersed in electro setting fluid. The fluid in between the electrodes solidifies to form the part. Once completed and drained, the unwanted material is trimmed. The advantages of this technology is part density, hardness, compressibility and other factors are controllable via appropriate value of current and voltage. The raw material are silicon, rubber, epoxy or polyurethane.

Laser-Assisted Chemical Vapor Deposition

Technique using gas phase conversion to solid structure with the help of pyro lytic process. This technique uses a laser beam focused perpendicular to the substrate in order to make sure deposition take place in the heated localized region. The laser power, pressure have considerable influence on the growth rate, bulk properties of fibre and diameter as well.

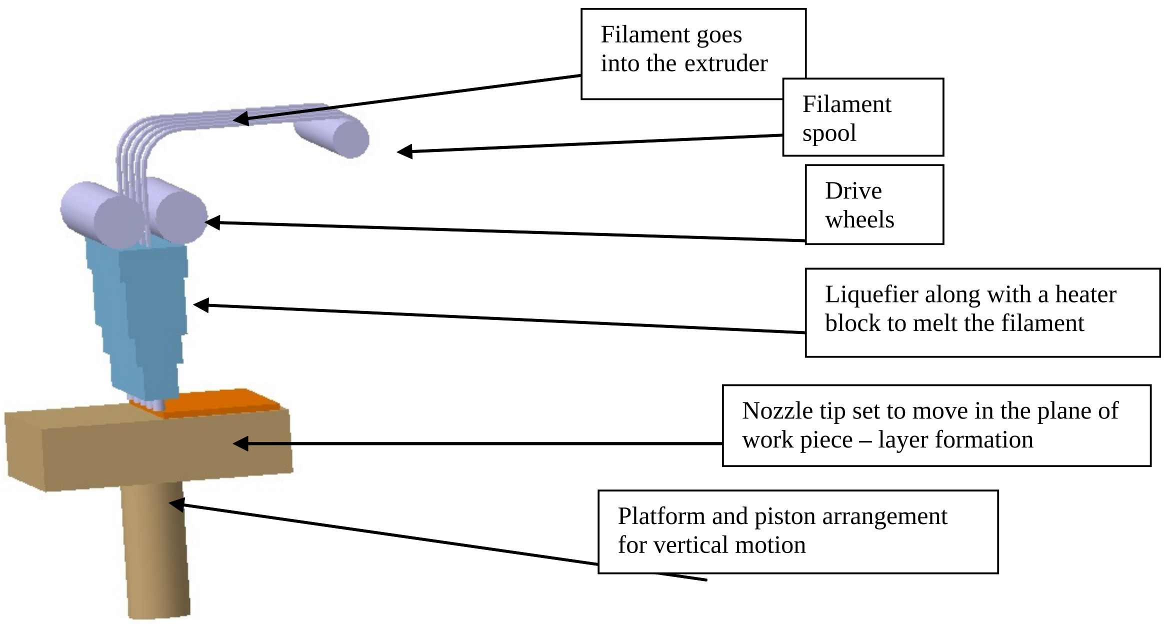
Desktop Milling

Instead of gradually building up of material, the work piece is created like n traditional machining. Since there is no deformation due to shrinkage, hence higher dimensional accuracy can be achieved. Any CNC machine can be used to make products from inexpensive material.

Fused Deposition Modeling

It is a rapid prototyping technique of generating 3D objects from CAD models. In this ABS plastic is extruded layer by layer from a temperature controlled head. The first step is creation of a 3D model with any available CAD package. The part is then converted to STL format and then transferred to FDM Quick slice software. The part is reduced to a set of triangles by tessellation. The primary advantage is that even the most basic component can be exported via any CAD system. However the resolution of the part is lost due to triangles and not splines and arcs.

Figure 10: Fused Deposition Modelling Setup



Ballistic Particle Manufacture

In this technique, molten material in form of stream is ejected from a nozzle and later separates into droplets and cold welding occurs to form the parts. The stresses can be reduced within the part if the substrate is rough and thermal contact between them is increased. The choice of stream depends on the application, can be either continuous or drop-on-demand. The stream is excited by a piezoelectric transducer with a frequency of 60 Hz. Temperature, change carried by the droplets and velocity of droplets characterize the part. The resolution of the droplets are around 50-100 micrometer. It advantages are cheap and eco-friendly, and produce fine grain structure.

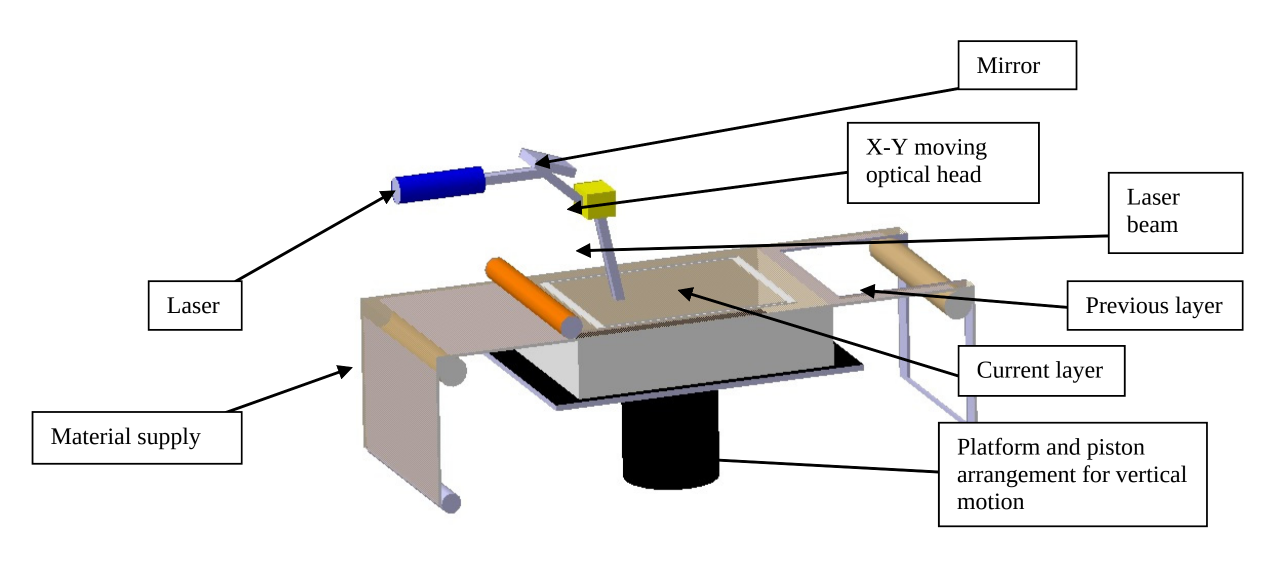
Solid Foil Polymerization

The part is built up of semi-polymerized foils and on UV light exposure, solidification takes place and bonding takes place to the previous layer. Upon illumination of the cross-slide, a new foil can be applied. The unwanted material acts as support and can be removed later.

Laminated Object Manufacturing

It is a robust and cost effective rapid prototyping technology with a variety of application. For examples in sand casting, ceramics processing and investment casting show how a reduction of cycle times and process steps can be achieved. The LOM equipment and process were designed to produce parts from paper. Using a modified LOM machine ceramic parts may also be manufactured where a computer controlled laser is used to cut through the ceramic. The cutting profile is generated by the slicing of the solid model. The process is repeated layer by layer to complete the solid object. Though this process leaves a lot of scrap but building speed is 5-10 times compared to other processes.

Figure 11: Laminated Object Manufacturing Process



Beam Interference Solidification

The process employs two laser beams operating with different frequencies and mounted such light emitted are at right angles, which then fall on resin kept in a transparent vat and polymerization takes place, the liquid is exercised cited to metastable state and then the second incident beam is polymerized to excite the resin. This isn't a commercial process and experiences many technical difficulties.

Three Dimensional Welding

It uses a robot with arc welding to on a simple shaped platform that may be converted into complex structure. The products here are not built using sliced CAD model. A relatively high resolution can be obtained. The critical thing here is, because of no feedback, prototype has a tendency to melt due to heat generation. Hence thermopiles are used to set up a feedback control system and control the temperature.

Gas Phase Deposition

In here, the reactive gas is either decomposed to heat or light. The decomposed solid then forms the part by sticking to the substrate. No commercial models are available yet. It is of three different types:

i. Selective Area Layer Deposition-The solid component is used to make the part. The parts can be constructed can be from carbon, silicon, carbides and silicon nitrides.

ii. Selective Area Laser Deposition Vapor Infiltration)-It spreads a covering of powder for each layer.

iii. Selective Laser Reactive Sintering - A solid part of silicon nitride or carbide is formed by reaction between the gas and the layer of powder..

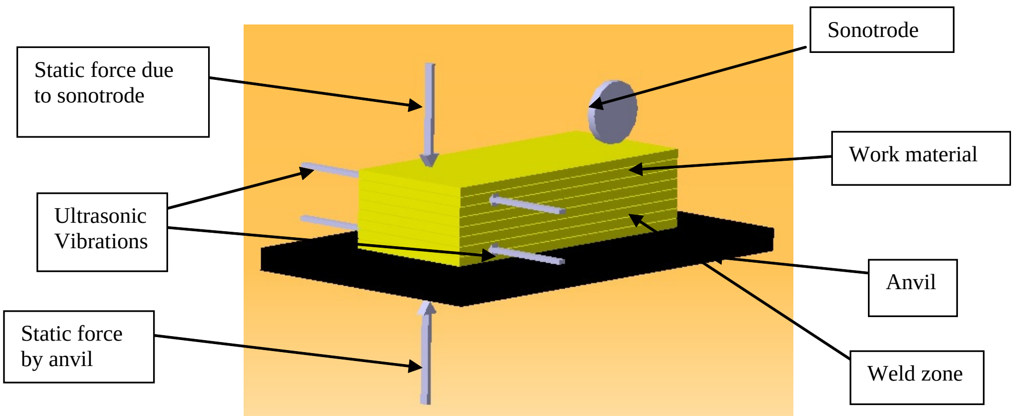
Spatial Forming

This process is used to produce parts with high precision ceramic pigmented organic 'ink' is used to cure the layer with UV light on a ceramic substrate. UV light is used to cure the layer and the process is repeated, until entire part is finished. 20% shrinkage in size occur due to sintering process.

Ultrasonic Additive Manufacturing

It is a layered type freeform fabrication process. It uses of low amplitude mechanical vibrations with high frequency, which induces static as well as oscillating shear forces which produces elastic-plastic deformation on work. This permits atomic diffusion to occur and tends to break up and disperse aluminum oxide. It is a solid-state fabrication process that combines layered manufacturing techniques and ultrasonic seam welding to form a solid freeform object. It can fabricate laminate metal parts by welding of layers to earlier material, the profile of every layer is created by contour milling. The process has great potential for injection molding tooling fabrication with, multi-material structures, fiber-reinforced composites, smart structures, and others (R J Friel and R A Harris, xxxx).

Figure 12: Ultrasonic Consolidation Method



APPLICATIONS

Rapid Prototyping has numerous applications with large variety. We have tried to classify them according to the techniques used as follows:

Stereolithography

Because of high surface finish and accuracy, this technique is used in making patterns for investment casting, RTV moulding and urethane. IBM has produced operating display units of ThinkPad tablet using stereolithography. It is also used in fabrication of small detailed parts and production of specialized manufacturing tools. Market prototypes especially used for presentation in trade shows are made using this method.

Selective Layer Sintering

This too can be used for producing pattern of investment casting. Also, durable parts, large parts like air ducts can be made. Since the accuracy is slightly less, so less detailed parts for form and fit testing and parts with living hinges are made using this technique.

3D Printing

Consumer goods, concept models, colour models for engineering related application, Turbines parts, castings and landscape models can be prepared..

Fused Deposition Modelling

This again produces specialized manufacturing tools, plastics with high temperature resistance, patterns for investment castings, parts for food-contacting application, small detailed parts.

Laminated Object Manufacturing

Used in making larger patterns for sand casting, RTV modeling, parts with less details for testing. Even in automobiles the deck parts are prepared from casting dies, these dies are made by LOM.

Solid Ground Curing

This can produce parts with more complex details than that produced by SLA. Form-fit assembly test, complicated patterns for investment casting, medical application, soft tooling.

Laser Engineered Net Shaping

Fabrication of aerospace equipments of titanium and other metals, repair and making of injection molding tools.

Electron Beam Melting

Since titanium is the most widely used material with this technology hence it makes this method available for various medical and aerospace components(turbine blades and pump impellers).It is used to produce replacements for the hip joint and various other implants. It is also widely used to make the turbo charger wheel for automobiles.

Shape Deposition Modelling

It can be used to create simple assemblies in a single operation. This can be used to create integrated assemblies where discrete assembly is difficult. Functionally ready prototypes like the components of the automobile, i.e. the engine components are made from it. Also injection moulds are prepared.

Ultrasonic Additive Manufacturing

The complicated 3D components can be fabricated from metal foils. Here aluminium is the most widely used material hence this process finds wide application in aerospace and tooling application. Also used for High

Temperature Superconductivity (HTS) application, magnetically levitated trains, for filtering the phone call signals and routing them, in embedded sensors and electronics.

Selective Laser Melting

Typical application include manufacturing of specialized complex materials, testing of quality prototypes and manufacturing of complex organic geometry.

Inkjet Printing

The application range from accurate patterns for casting to art, jewellery and form-fit testing.

Paper Lamination Technology

It has too many applications. From modeling, silicon mould application, sand and vacuum casting to prototypes , Industrial models, test models etc.

Jetted Photopolymer or Photopolymer Phase Change Inkjet

Form fit testing, rapid tooling patterns, very detailed parts like jewellery and fine items.

Desktop Milling

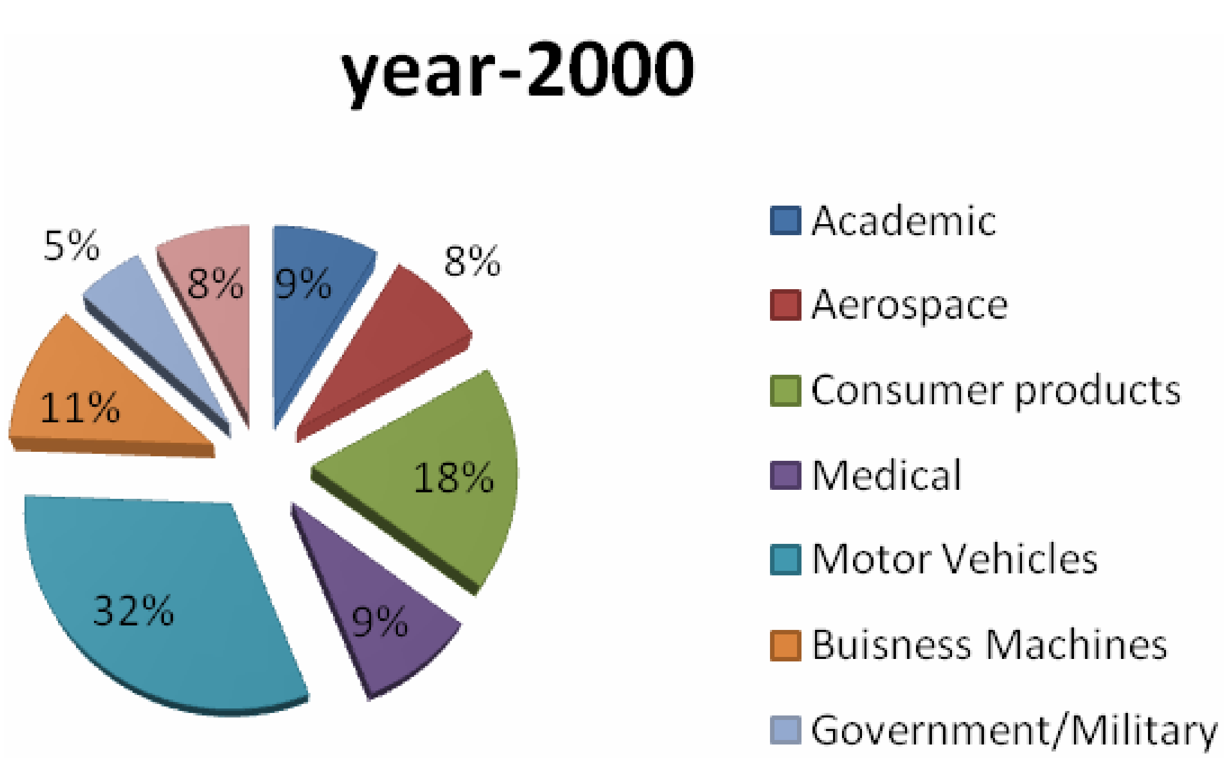
Functional prototypes, moulds and models, injection moulds and jigs.

Ballistic Particle Manufacturing

Mainly used for concept visualization. The parts produced cannot be used for functioning due to weak material, useful in design process.

GENERAL APPLICATIONS

Figure 13: Percentage Use of Rapid Prototyping Worldwide as of Year 2000, Data Based on D.T. Pham, S.S. Dimov, Rapid Manufacturing Verlag 2001, ISBN1-85233-360-X, Page 6



Aerospace Industry

Various components of the satellite are made by laser sintering, electron beam melting, ultrasonic consolidation and Laser Engineering Net Shaping(LENS). British Airbus Engineers aimed to print out an entire aircraft wing (2011).

Automotive Industry

Shape Deposition Modelling for production of engine components, URBEE is to be the world's first 3D printed car. The deck parts of automobile are produced by Laminated Object Manufacturing. Electron Beam Melting is used to prepare turbocharger wheel of diesel engines.

Machinery Industry (Tooling)

It has a major market in direct part manufacturing. Currently methods like EBM, LENS, UC, SLS, SLM and DMLS are being used, Stereolithography, Selective Layer Sintering, Fused Deposition Modelling and Solid Ground Curing are used for producing patterns for investment castings. Paper Lamination Technology has vast application here as stated. LENS is used for making injection molding tools.

Medical Industry

Implants, improve tissues with 3D printed vascular network made from sugar, even 3D printed human jaws for implants.

Manufacturing Industry

Sales and marketing of consumer based products like shoes, clothes, other footwear, titanium necklace and other jewellery is prepared directly from direct laser sintering and jetted photopolymer.

RP PROCESSES UNDER DEVELOPMENT

Liquid Thermal Polymerization

In this process the resin is thermosetting and it utilizes an infrared laser to create voxels. This is similar to Stereo lithography. Heat dissipation causes shrinkage and unwanted distortion in the part; also it affects the size of the voxels. However, these are controllable and far better than SL. This technique is still a part of research and development.

Liquid Metal Jet Printing

It is a freeform solid manufacturing process. Here the molten jet is printed by controlling it to specific location. The process is similar to inkjet printing unlike spray forming. The diameter of molten sphere ranges from 100 to 1000 microns, and can be changes by changing the orifice size.

Currently research on developing of an aluminium printing of mechanical parts in being carried out.Earlier research work includes jetting copper, metal ball generation and solder mask for circuits.

Robo Casting and WireFeed

A new variant of the existing technique i.e LENS using material in the form of wire known as Wire Feed process is being developed, similar is another forming process using ceramic as raw material called Robo Casting by Sandia labs.

Direct Photo Shaping Technology

This institute is developing a process similar to stereolithography which uses a DMD for exposure. The technique is known as Direct Photo Shaping Technology developed for metals and ceramics by SRI International.

US Army, Mobile Parts Hospital

The U.S. Army is working on developing medical units for soldiers in the battlefield. According to the available report, this is a 20 foot portable container with facilities on spot to scan a broken bone and develop a new one using LENS, a Rapid Prototyping Technology.

Advanced Ceramics Research, Inc. Tucson, AZ

It has developed a high pressure fused deposition system, which is can be used with numerous engineering polymers like polycarbonate (Lexan), polyaryletherketone (PEEK), polymethylmethacrylate (PMMA), and thermoplastic polyurethane (Pellethane)

Other Success Story

A Rapid Prototyping system which uses solid feedstock, extruding components using solid powders/fibres in the form of fillers to the feedstock. This process is known as Extrusion Freeform Fabrication.

The U.S. Government is also funding the development of functional polymer matrix components.

CONCLUDING REMARKS

First steps into the rapid prototyping technology initiated in 1988, based on first SLA technique [28]. In leading countries automotive and airplane industry different applications were realized. A lot of specialized service offices are acting successfully.

From the above literature review, it is clear that there are a numerous areas such as process selection, material selection, layout planning, volume modeling, simulation which require advanced and newer approaches despite the current technological advancements in the field of RP. It is also clear that are several research issues which need to be addressed in RP especially in layout planning and part deposition planning.

Despite this progress many challenges still lie ahead. First, efficient data flow and data handling of 3D objects need attention. Second, optimization accuracy by better technical solutions for calculating/avoiding shrinkage, distortion curing, post curing and post curing distortion, geometric slab distortion, creep, etc. Third, material behavior improvement. Fourth , mastering new processes meeting specific manufacturing industry demands.

However barring these developmental issues, the contribution of RP to the manufacturing sector has been tremendous. The applicability of these processes can be further improved. This can possibly be done by: First, systematically evaluating the critical influencing parameters. Second , by efficiently and effectively combining these technologies with conventional manufacturing methods. Third, extensive investigation of new and innovative domains.

In addition, a probable solution to the aforementioned discussion would be to find optimal strategies for obtaining good part deposition of the parts in the machine volume by improving part accuracy, improving surface quality, reducing the build time, reducing amount of support structures and cost subject to RP process constraints, , good packing by minimizing build time and requirement of support structure volume, maximize machine volume utilization and produce high quality plate subject to RP process constraints; formulating some basic build rules to aid designers in order to improve the strength of the parts made on the RP machine by controlling parameters like: Bead width, Air gap, Model build temperature, Raster orientation, color, etc. subject to RP process constraint; developing better frameworks for designing and manufacturing functionally gradient products; develop a framework to reduce anisotropy in the products manufactured by fused deposition modelling technique at the design stage itself subject to RP process constraint.

Obtaining optimal strategies to the aforementioned areas would go a long way in leaping forward to rapid manufacturing and bringing rapid prototyping and rapid manufacturing at par with the conventional manufacturing process techniques.

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