Latest trends in Additive manufacturing

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Abstract. Additive manufacturing is the most recent and the most revolutionary technology in the production industry. It is an unconventional method of manufacturing. In this manufacturing method, material is added one layer upon another layer to get the required shape and size of object. Most complex objects can be built very easily by this technology. Additive manufacturing has the capability to reduce the supply chain by reducing a number of processing stages of a product. Additive manufacturing technology developed a lot from the day 3D printing technique, introduced as Stereolithography in 1984 by Charles W. Hull. Today we have different types of 3D printing techniques such as polymer resin based printing, wire based printing (FDM) and powder based printing (SLS) and some hybrid Additive manufacturing like High speed sintering. Additive manufacturing has applications spread from Aerospace industry to Toy industry and from Biomedical industry to Construction field. Additive manufacturing leads to "Social manufacturing" which involves customers in all stages of product manufacturing. Most of the large scale industries are investing a large capital in R&D for this 3D printing. Many startups are entering into the market each day. Today bio-compatible kidneys, bones and even hearts are bio printed, multi-storey buildings have already been 3D printed and research works are in progress. Now researchers are stepping towards 4D printing which uses "Intelligent" materials which can be coded. Research work is being done on different Additive manufacturing techniques and different materials and process parameters. This paper is a review of Additive manufacturing and it's latest trends. The Trends related to printing technique as well as materials.

Keywords: 3D printing, Additive manufacturing, Stereolithography, Selective laser Sintering, Selective laser melting, Bio-printing, Fused deposition modeling.

1. Additive manufacturing
AM is similar to ink jet printing on paper but added with the 3rd dimension. The Additive manufacturing involves designing, slicing printing, printing the object, post processing and inspection and testing. In designing phase 3D models are created by using some computer aided software packages. These designs either be created manually on a CAD software or be generated automatically by using scanned data and digital image processing then by using some software packages. These CAD files are saved with Standard Tessellation Language (STL) having .STL extension. These .STL files then transferred to slicing software packages. Generally the 3D printer manufacturing companies will provide their own slicing software packages. Some online platforms are also providing these slicing software packages which can be compatible with the printers. This slicing software will slice the 3D model into a number of 2D planes and generate the G-codes and M-codes automatically for each layer and save this data in a format which
can be read by the 3D printer. The 3D printer will read the data and will print the product in layer by layer manner.

![Figure 1. basic phases of Additive manufacturing](image)

While printing, the printer will follow the instructions generated by the slicer software and material extruder, photo curing light, laser light and base table will move accordingly. There are different types of additive manufacturing techniques available based on material feeding and curing techniques from the beginning but only few of them are commercialized and became popular. After making products some post processing like finishing, cleaning, heat treatment etc. should be performed depending on the type of printing technology.

2. **AM processes**

Additive manufacturing is an umbrella term under which different manufacturing techniques are available. Additive manufacturing techniques are generally based on the form in which the material is being used. Different AM processes are based on material form are:

- Photopolymer resin
  - Stereolithography (SLA)

- Metal sheets
  - Laminated object manufacturing (LOM)

- Wire material
  - Fused deposition modelling (FDM)

- Powder material
  - Selective laser sintering (SLS)
  - Selective laser melting (SLM)
  - Direct metal laser sintering (DMLS)

However some hybrid techniques like Direct energy deposition, High Speed Sintering etc., are being developed for improving quality and to reduce time consumption. Out of different techniques, Fused deposition modeling (FDM) and Selective laser sintering/ selective laser melting (SLS/SLM) are most commonly used.
Figure 2. (a) Fused deposition modeling  (b) Selective laser sintering / Selective laser melting (c) Stereolithography (d) Laminated object manufacturing [1]

2.1. Fused deposition modeling

FDM is the most commercially available printing technique. It is famous because of its low cost, ease of printing, flexibility in materials, ease of material availability and its applications. These printers use material in the form of wire. The wire will pass through the print jet. In the print jet hot extrusion of the material will take place and sends semi molten material out from the nozzle. Continuous supply of material is provided by the spool of material. The extruder will deposit the material which fuses later. The extruder will move in the contours defined by G-codes and M-codes generated by slicer software. After printing one layer, the extruder will print the next layer up on the previous layer of the component. Most of the FDM printers are available in the form of desktop printers and are very easy to use. Most of the FDM printers use plastic as a feed material however few models use metal wires also. The parts produced require less number of post processing operations so that we can find FDM printers even in some schools also [2].

Thermoplastic materials such as Acrylonitrile Butadiene Styrene (ABS) and its variations, nylon, ply-lactic acid, polystyrene, polycarbonates and thermoplastic urethane.MED610, a raw material that Stratasys provides is bio-compatible etc. are used as the feed material for the FDM printers. The printed part strength varies from material to material and it also depends on some process parameters. The process parameters include layer height, initial layer height, line width, wall thickness, top/bottom surface thickness, infill, printing nozzle temperature, build plate temperature and print speed. Here time and the quality of product both are contradicting each other. If we want a quality product we need to compromise with time vice versa., Multi color as well as multi material 3D printing is possible with this type of 3D printers [3].

Even though most of the FDMs are using plastics as a material, some FDM printers use metals and metal alloys as printing material. These 3D printers are named as FDMm (Fused Deposition Modeling metal printers). These FDMms may use different deposition techniques while printing. One of those techniques is by using a heater in the depression nozzle for melting the wired material which is the same as FDM for plastic material. Electrohydrodynamic redox printing (or EHD-RP) is another FDMm that utilises electrochemistry to synthesise metallic deposits. Here focussed electrohydrodynamic ejection of metal ions dissolved from sacrificial anodes and their subsequent reduction to elemental metals on the substrate [4]. FDM is mostly used in 3D printing technique. But this is limited to print polymer parts only while
Selective Laser Sintering can build both polymer as well as metallic parts. Selective Laser Melting is a dedicated printing technique for metals only. In addition to prototyping, Additive manufacturing can compete with conventional manufacturing techniques in mass production and the metal additive manufacturing can help for mass manufacturing [5].

2.2. Selective Laser Sintering/ Selective Laser Melting
Selective Laser Sintering uses material in powder form. Selective Laser Sintering or Selective Laser Melting is the most dominating printing technique because it allows printing with metals. Metals have the capability to withstand loads like tensile, compressive, impact, fatigue, creep loads. SLS using powdered material which is cured by high intensity laser beam. Different powder manufacturing methods are available as in the case of powder metrology. Some binders are added to the powdered material to improve the properties. The powder material can be plastic as well as metal also, but the SLS/SLM preferred to use metals as the powders. While printing the part the material is spread on the printer bed with the help of a roller for one thin layer. Laser now focuses on the powder bed selectively in the path decided by G and M codes generated by the slicer software. This laser melts the powder material and fuses together. After sintering on one layer, the roller will move on the powder bed and spread the powdered material on the previous layer then the laser will cure the powder selectively. This process will be repeated until the completion of the entire product [6]. In this type of printing, the loose powder of the previous layer will act as the support material for cantilever parts. So, no need to use additional support material as in the case of FDM. The loose powder after sintering can be reused for many numbers of cycles.

Different binding techniques are available in the powder bed additive manufacturing. Solid state sintering (SSS), uses heat energy between the temperature range from half of melting point temperature to the melting point temperature. The diffusion is the most important process in this SSS. It involves neck formation between the powder particles and sintering occurs by lowering the free energy between the powder grains. A wide variety of materials can be processed by this method. Chemically induced binding uses self binding property. In this binding method, particles are heated to higher temperatures so that disintegration of particles into elements occurs. The disintegrated element bonds with oxygen and forms oxides which acts as a binder. Liquid phase sintering can be a partial melting or a full melting process. Liquid phase partial melting can be classified into two groups based on usage of binder material. In one group, a binder material and a structure material are used. These binders and the structure materials can be in separate powder form or each grain of powder can be a composite of structure material and binder material or the structure material can be coated with a binder material. Here the heat source melts the binder material and sintering occurs by lowering the free energy between the powder grains. A wide variety of materials can be processed by this method. Liquid phase partial melting can be classified into two groups based on usage of binder material. In one group, a binder material and a structure material are used. These binders and the structure materials can be in separate powder form or each grain of powder can be a composite of structure material and binder material or the structure material can be coated with a binder material. Here the heat source melts the binder material and sintering occurs by lowering the free energy between the powder grains. A wide variety of materials can be processed by this method. Liquid phase partial melting can be classified into two groups based on usage of binder material. In one group, a binder material and a structure material are used. These binders and the structure materials can be in separate powder form or each grain of powder can be a composite of structure material and binder material or the structure material can be coated with a binder material. Here the heat source melts the binder material and sintering occurs by lowering the free energy between the powder grains.
easy to control when compared to liquid phase full melting or Direct Metal Laser Sintering (DMLS) Selective Laser Melting (SLM) because in SLS structure material does not melt so that viscosity is more. But in DMLS, the structure material will also melted so viscosity is minimum. As viscosity is minimum and because of surface tension of liquid metals, it is difficult to control the metal flow during the printing process. As there is full melting of structure material, porosity of the final product is least and density of the part is maximum so no need to do post processing operations for increasing the density.

2.3. Stereolithography

Stereolithography is the pioneer of Additive manufacturing technology. This technology uses photocurable polymeric resin as a printing material. These photosensitive materials are cured by a photochemical process. Ultraviolet light is used as a source of energy and cures by cross linking the polymers with each other and converts liquid phase resin into solid phase layer by layer. The stereolithography can be either bottom down type or bottom up type. In bottom-down type of stereolithography, the base table moves down into the polymeric resin in steps wise for each layer of printing while the UV light source will focus on the vat of polymer. In the bottom-up layer, the UV light source will be inside of the resin while the base plate will move upwards.

There are three types of resin printing technologies available based on the method of light source used. In the first type it is the UV laser which is used to draw the predefined design or shape defined by slicing on the surface of the vat of polymer resin. In this laser intensity, hatch spacing and thickness of the layer will define the resolution of the printed part. The strength of the part printed in this way will depend upon the layer thickness. As the layer thickness is minimum, the strength will be maximum [9]. The second type uses Digital light processing (DLP) projector as the light source for curing the resin [10]. DLP projector consists of a digital mirror device (DMD) which has thousands of mirrors and each mirror has a size of order of red blood cells. Light is selectively directed using DMD and cures the whole layer at a time. Here light comes from a small source to cover a wide area. This has the chance of distorted pixels at their edges. For best resolution smaller parts are preferred by DLP type of 3D printers. In the third type, the light source is a liquid crystal diode (LCD) projector [11]. It uses an array of UV LCDs. Light from the flat LCD panel shines directly in a parallel fashion on the vat of polymer. Here it is similar to the DLP projector and prints the whole layer at a time. In LCD, light does not expand. So, pixel distortion is not an issue with LCD printing. The more pixels it has, the better print quality it gives.

2.4. Laminated object manufacturing

In LOM printing technique, parts are made by sticking sheet material one up on another. The required part of the sheet from continuously supplied sheet material is cut by a laser and this part of sheet is then made to stick by applying some adhesives, external pressure and by heating. The adhesive coating is applied to the bottom side of the sheet. A roller used for the hot-pressing process. Properties of the printed part can be varied by changing the temperature, pressure values of the roller and by applying the pressure and temperature separately [12].

3. Materials

Based on the type of application and availability different materials are being used in Additive manufacturing. Mainly there are two phases of material used i.e liquid phase material and solid phase. The earliest is the pioneer material for the revolutionary 3D printing technology. The stereolithography uses material in liquid phase i.e thermosetting photocurable polymeric resin. The former one is in solid form which can be either wired form or powder form. Based on the printer manufacturers different materials available in each form of materials.
Table 1. Categories of materials available for Additive manufacturing.

| Material type | Material form | Printing technique |
|---------------|---------------|--------------------|
| 1 Plastics    | 1.1 Photo curable resin | 1.1.1 Stereolithography (SLA) |
|               | 1.2 wire       | 1.2.1 Fused deposition modeling |
|               | 1.3 Powder     | 1.3.1 selective laser Sintering |
|               | 2.1 wire       | 2.1.1 Arc welding technique |
|               | 2.2 powder     | 2.1.2 Direct energy deposition |
|               | 2.3 sheets     | 2.2.1 selective laser sintering |
|               | 2.2.2 Selective laser melting |
| 2 Metals      | 2.2 powder     | 2.3.1 Laminated object manufacturing |
| 3 Ceramics    | 3.1 Powder     | 3.1.1 Selective laser sintering |
|               | 4.1 Powder     | 4.1.1 Binder jetting |
| 4 Cement      | 4.2 Cement slurry | 4.2.1 Fused deposition technique |
|               | 5.1 Resin      | 5.1.1 stereolithography |
| 5 Bio-ink     | 5.2 wire       | 5.2.1 Fused deposition modeling |

4. Processing parameters to control

There are many parameters that can decide the quality of the final product. Generally the quality of the final product depends on the design data generated by the designer, material properties and machine parameters. Different parameters influencing the quality of FDM, SLA and SLS/SLM printing techniques are mentioned in table 2. In the market various varieties of materials are available and each material property will vary from one manufacturer to another manufacturer. It is because of a lack of standardization in making of the materials. Several initiatives have been taken by several organizations around the world and several institutions like International Organization for Standardization (ISO),
Additive manufacturing society of india (AMSI), American Society for Testing and Materials (ASTM), with the help of projects and technical groups focused on the standardization of AM [13]. The influence of material properties can be eliminated by standardization of powder material. While manufacturing a product by 3D printing machine we are available with many process parameters.

Table 2. influencing parameters on product quality [18][19][20]

| Material properties (SLS/SLM) | Process parameters (SLS/SLM) | Process parameters (FDM) | Process parameters (SLA) |
|--------------------------------|-------------------------------|--------------------------|--------------------------|
| Viscosity                      | Laser power                   | Layer thickness          | Liquid resin depth       |
| Surface tension                | Scan speed                    | Build orientation        | Curing time              |
| Particle size                  | Scan path                     | Raster Angle/ Raster orientation | Post curing time         |
| Particle distribution          | Raster angle                  |                          |                          |
| Particle shape                 | Scan vector length            | Air Gap                  | Part orientation         |
| Absorptivity                   | Laser type                    | Extrusion temperature    | Curing temperature       |
| Reflectivity                   | Hatch spacing                 | Print speed              | Temperature of previous layer |
| Thermal conductivity           | Print bed temperature         | Infill pattern           | Photo initiator concentration |
| Specific heat                  | Layer thickness               | Infill density/ Interior infill percentage | Intensity of UV light |
| Emissivity                     | Melt pool size                |                          | Absorptivity of photo initiator |
| Melting temperature            | Intensity of heat source      | Nozzle diameter          | Fill spacing             |
| Component ratio                | Scan radius                   | Raster width             | Fill cure depth          |
| Chemical composition           | Gas flow                      | Number of contours       | Line width               |
| Powder density                 | Orientation of the part       | Contour width            | Hatch spacing            |
| Powder porosity                | Pre heating                   | Contour to contour Air gap | Hatch overcure           |
|                                | Wavelength of laser Machine   |                          |                          |

These parameters will vary from machine to machine. By controlling these machine parameters we can control the quality of the final product according to our requirement. But it is difficult and very costly to choose each and every parameter available for controlling. The process parameters are to be selected based previously available data on their influence on the final quality of product. Design of experiments (DOE) are experimentation techniques for optimization of process parameters. Different design of experiment techniques like One-factor at a time, Taguchi, ANOVA, Genetic algorithms, Artificial neural networks (ANN) etc., are available to develop the process parameters and optimization of process parameters. For a specific property optimization, many experiments are needed in a trial-and-error approach that will lead to a high cost of the SLS process. One factor at a time is one approach. It reduces the number of experiments. But the problem is that it will not consider mutual interaction of parameters.
Full Factorial and fractional factorial mutual interaction of parameters is considered. Aboma Wagari Gebisa et. al., [14] have used five process parameters: air gap, raster width, contour number, raster angle and contour width for investigation of tensile properties of ULTEM 9085 in the FDM process with the help of full factorial design of the experiment method. Raster angle, road width, air gap, Layer thickness, number of contours and build orientation as primary parameters in investigation of dynamic mechanical performance of FDM/ABS printed parts through ANOVA design technique [15]. Deng X, Zeng Z, Peng B, Yan S, Ke W [16] have used Layer thickness, Print speed, Infill density/ percentage and Extrusion Temperature as process parameters and used Taguchi as experimentation technique. Gebisa0F A.W., Lemu H.G have used Air Gap, Raster angle/Raster Orientation, Raster width, Number of contours/Shells and Contour width/Shell width as process parameters and used ANOVA as experimentation method for optimising Tensile Strength and Tensile strain [17].

5. Opportunities

Additive manufacturing in its early days didn’t find new opportunities because of patent restrictions. But after expiry of patents it is growing opportunities into many fields. From the past two decades AM spreading its applications to

5.1. Manufacturing

Prototyping in one of the product development processes. After conceptualization of market need, before manufacturing a component in full scale a scaled component will be produced. This scaled product is called a prototype. The prototype helps in analysing the part and for communicating the idea of the product to the customers. As on spot manufacturing is possible with Additive Manufacturing, It has application in prototyping. Additive manufacturing technology is rapidly growing in prototyping stages. This additive manufacturing avoids tooling like moulds, cutting tools etc., and can easily produce very intricate shapes easily. So, the number of assemblies in a component can be reduced which leads to an increase in rate of production as well as reduces production time. Instead by a big manufacturing plant only one desktop 3D printer can build a required component. So that it reduces manufacturing plant space. Multi Material additive manufacturing is a recently growing technique where more than one material can be used for tailored properties of the final part.

5.2. Supply chain management

Additive manufacturing leads to drastic changes in Supply chain management. It will lead to mass customization of components. Social manufacturing [21] is possible with AM so that people can get which model or component they want instead of choosing from the available components. Social manufacturing or on demand manufacturing is one of the opportunities from AM. It will help in reduction of inventory cost of parts. Social manufacturing enhances the “human-machine interaction” quality. A personalized product according to the customer’s need can be designed online, during the design stage of a product, a product can be tested and its user experience can be achieved virtually with 3D model display. It helps user’s desires to be simulated and product consumption is then increased. Whenever a product is required, customers just open the product data file and press the “PRINT” button, and then the product can be printed out [22]. The social manufacturing model will help individuals with the 3D printers to participate in manufacturing the parts that are needed by the customers [23]. Democratization of manufacturing has been taking place where people can print the parts of their choice. Today most of the schools had their own FDM printers. Many households prefer to purchase FDM printers for making products like spare parts and toys for their children at their home of their choice. For the cinema industry these 3D printers are the must. The manufacturing industry especially in the design phase these FDM printers are used for prototyping. Some FDM printers are already installed in the International Space Station for making spare parts because it is difficult to make parts by other traditional manufacturing methods. These FDM printers are also used in some rescue operations at remote locations where it is difficult to find any spare parts. In addition to printed parts people are willing to purchase these 3D printers which became a new market opportunity to the printer manufacturers.
5.3. **Aerospace**

AM to revolutionize the aerospace manufacturing industry, with impacts to production lead time, acquisition cost, and performance envisioned. In general aerospace uses very complex structures. Each component of an airplane is a combination of multiple intricate components. Additive manufacturing helps in reducing part count per component. General Electric company used AM for manufacturing of Fuel nozzles for jet engines. In general the fuel nozzle has 20 parts. They have redesigned the fuel nozzle and reduced the part count from 20 to a single component. GE included 20 components into a single component and printed as a single part. so that they reduced the inventory by 95% and 5 times more durable [24]. Additive manufacturing can print very complex shapes very easily. It helps in producing lighter parts with similar strength that produced by conventional manufacturing methods. Reduction of weight is very useful in the aerospace industry because it will increase the efficiency of the engine. Rib-Web Structural Components, Turbine Engine Cases, Engine Blades and Vanes are examples of AM printed parts in the Aerospace industry [25].

5.4. **Bio printing**

5.4.1. **Tissue printing.** The application of AM in medicine is named as Bio-printing. Human organs are difficult to create manually by cad modeling, we use CT or MRI scan. MRI (magnetic resonance imaging) uses powerful magnetic fields and radio frequency pulses to produce detailed pictures of organs and other internal body structures. CT scans utilize X-rays to produce images of the inside of the body. These images then are digitally processed. These digital processed models are then modified by using CAD software. Then as usual sliced and then transferred to the printer. In tissue printing, the material used is Bioink. Bioink is a solution of a biomaterial or a mixture of several biomaterials in the hydrogel form, usually encapsulating desired cell types. This bioink can be crosslinked or stabilized during or immediately after bioprinting to generate the final shape, structure, and architecture of the designed construct [26]. Bio-ink is a material which can be compatible with that particular person's body. Stem cells from the person for whom the part is being produced will be collected and these cells will be developed in the laboratory. These bio-inks will be converted into wire form. The printing can be extrusion of wire based material. After printing the part will be kept in an incubation where cell development will take place. Bioprinting is able to make functional tissue constructs to replace injured or diseased tissues. It is a relatively new approach that provides high reproducibility and precise control over the making of parts.

5.4.2. **Medical implants.** Medical implants which are used in replacement of broken bones musculoskeletal systems. These parts are of irregular and very intricate structures. 3D printing techniques such as SLS/SLM has been extensively used for manufacturing these parts. Materials that are biocompatible and stable over a long period of time have been used in implant printing. Pure metals can't be used as material for body organs because pure metals can degrade easily. So, metal alloys are used for printing bone implants. Most of the bones are manufactured from surgical grade 5 titanium alloy(Ti-6Al-4V). Some ceramics and Polymers are the mostly used alloplastic materials [27]. Some implanted alloys are generally fabricated with Additive manufacturing from stainless steels (SS), Co/Cr-based alloys, titanium and its alloys [28], [29]. Some shape memory alloys like NiTi are also used. Shape memory allows NiTi implants to be initially deformed by refrigeration and then return to their predefined shape at body temperature which is a useful property for the deployment of stents [30].

5.5. **Food printing**

Food manufacturing with customized shape, color, flavor, texture, and even nutrition is possible with the Food printing process. Three-dimensional (3D) food printing can revolutionize the food making process. By this method food products can be customized and fabricated to meet individual needs. It enables us to control the amount of printing material and nutrition content. Three types of printing materials (i.e., natively printable materials, non-printable traditional food materials, and alternative ingredients) and two types of recipes (i.e., element-based recipe and traditional recipe) have been used.
for customized food fabrication. Essentially, 3D food printing provides an engineering solution for new food product development, and a potential machine to reconfigure a customized food supply chain [31]. Simplifying supply chain, and broadening of the available food material are opening the scope of food printing. Currently, 3D printing is being applied in food areas such as elderly food, sweets food, military and space food etc., [32].

5.6. Construction printing
Nowadays for construction of a building at least takes 6 months and complex shapes are difficult to build by conventional construction techniques. 3D construction printing gives greater freedom and flexibility in architecture. 3Dcp can build the same construction in 2 to 3 days. This printing technique is named as Material Deposition Method (MDM). The printer can be a computer controlled 4 axes gantry type or six axes robot type. Out of the two techniques, 4 axis gantry is mostly used and for complex shape printing, 6 axis robot printer is most preferred. Contour crafting is one of the MDM techniques where extruder is the combination of nozzle and trowel. The trowel guides the printed material to create an exceptionally smooth and accurate surface. The Trowel can be deflected at different angles to create various non-orthogonal structures. Concrete mixture passes through the pipes to the extrusion nozzle then extruded out in a pre-decided manner.

5.7. Printed electronic circuit boards
Additive manufacturing technology has been successfully utilized in multi-layered PCB circuit manufacturing, which can reduce the lead time from the PCB design to prototype PCBs. Currently used subtractive or hybrid processes that involve wet chemical processes can be replaced by direct ink printers to obtain a rigid PCB. Fabrication of a double-sided PLC is also possible with 3D PCB printing. This technology involves the deposition of conductive materials in a highly viscous liquid state. High viscosity helps to retain their shape after deposition. Highly viscous silver nanoparticle (AgNP) ink was used as the printing material which has excellent conductivity and better mechanical reliability. The printing was done through a small nozzle of ink extrusion printer. The PCB layout can be designed using conventional PCB softwares. The nozzle size, ink feed rate, printing speed, and other parameters were adjusted to obtain an optimal printing quality. With a minimum pin-to-pitch printing resolution of 100mm, our 3D PCB fabrication method satisfies most conventional PCB design rules and modern integrated circuit pack-aging requirements [34].

5.8. Textile printing
Because of its zero wastage property it has many opportunities in apparel, fashion designs and jewelry making. Similar to architecture in construction, these apparels, fashion design and jewelry require more degrees of freedom in making complex parts. 3D printing technology is widely used in these fields [33].

6. Future application research gap
As additive manufacturing is a recently growing technology, there have been many limitations to overcome and many applications to be explored. Following are the some of the future and ongoing developments and research gaps in the field of AM:

6.1. Hybrid 3D printing
This EHD-RP allows multi-metal and alloy printing from a single nozzle. Another technique in metal deposition is the use of Gas Metal Arc Welding [35]. Here instead of a print jet and electric heater, material is melted because of the arc. The controlled deposition of material achieved by movement of electrode and base table by the instructions of G-codes and M-codes. Here inert gas is provided to separate the printing area from the atmosphere. It is very difficult to control metal in its molten state. So we have to compromise with the resolution and dimensional accuracy of the final product. Finally the Direct Energy Deposition (DED) method. This is the most recent and the fastest 3D metal printing process. Here we may use a laser, plasma or electron beam as an energy source for melting the feed
material and then the molten metal can be deposited wherever it is required according to the codes generated by the slicer software. But the major problem with the DED is that we have to compromise with the resolution of the final object produced.

High Speed Sintering is the combination of binder jetting and melting. Time consumption in the case of SLS and SLM is more because the laser has to travel the path generated by the slicer. In some machines more than two lasers are used to minimize the time to trace the path. In HSS lasers need not to trace the path instead Radiation Absorbing Material (RAM) will print on the desired area and then sintered using an inexpensive infrared lamp. This binder will help in binding the powders as well as to concentrate and absorb more amount of the heat when compared to the support material to melt that required portion [36], [37].

MIT has initiated the concept of 4D printing. 4D printing is a recent development of 3D printing, shows promising capabilities and broad potential applications. It completely depends on mathematical modeling and design, smart materials and 3D printers. 4D printing shows advantages over 3D printing in several aspects. 4D printing can make dynamic structures with adjustable functionality, shapes and properties. This capability can be achieved by appropriate combination of smart materials in the three-dimensional space. Mathematical modeling is required for the design of the distribution of multiple materials in the structure. There are minimum two stable states available in a 4D printed structure, and the structure can shift from one state to another under the corresponding stimulus [38], [39].

6.2. In-situ monitoring

As of now we can collect the data related to in situ-measurements or online measurements of the part while it's being printed with the help of feedback system by implementing in situ infrared (IR) thermography high speed camera and digital CCD cameras AM technologies[40], [41]. Works are in progress in situ monitoring which enables the data collected from the sensors through the feedback system to analyse and compare with the target design data. If there are any deviations from the targets the system will be able to set the process parameters such as laser power, hatch spacing, speed etc inorder to control the quality of the part while it has been printing. So that it can assure more reliability and quality in the product.

6.3. Topology optimization

AM can also produce topology optimized objects. Topology optimization is a numerical approach that identifies where material should be placed in a given domain. For a given set of loads and constraints, topology optimization can facilitate minimal material usage of weight or uniform stress distribution. Macro structure topology optimization considers that a structure is composed of a single homogeneous material and that material is either present or absent in each part of the design domain. Aerospace and automotive industries [42] where weight reduction can lead to substantial energy savings over the life of the product, topology optimization maximizes efficiency. Topology optimization has also been application in biomedical implants [43], investment casting processes, and more [44]

6.4. Smart manufacturing

A 3D printer generates a large amount of data during printing a part. This data is related to the materials, process parameters and its influence on output quality. Machine learning can use this data for choosing suitable material for a particular application and this machine learning can even set the process parameters for the required set of applications [45]. 3D printing along with information technology and Artificial intelligence will be a key player for smart manufacturing or industry 4.0.

6.5. Standardization

Assurance of quality is a major issue with Additive manufacturing. Lack of standardization in material and machine is one of the main factors of the problem while the gap in the simulation part is another important factor. Different standards development organizations (SDOs) are working on developing
standardized tests for measurement of the key mechanical properties including tensile strength and fatigue resistance etc., [46].

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