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Technological Advancements in Metal Additive Manufacturing Process – A Review

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Abstract: Additive Manufacturing/Rapid Prototyping is the latest developing technique used in manufacturing complex geometrical products, with different applications. This paper is mainly focused on review of various technological advancements in metal 3D printing processes. Metal Additive Manufacturing creates a new path in aerospace, defense & automotive applications for manufacturing lightweight, consolidate assemblies having complex geometries. There exist challenges in developing new design methodologies to utilize AM-enabled products, while minimizing the cost and weight. These technologies are also used for manufacturing dissimilar components with more accuracy. The target of this paper is to analyze the most recent kind of metal added substance measures like Powder Bed Fusion and Direct Energy Deposition and have an outline of ongoing metal AM advancements.

1. Introduction

Additive Manufacturing/Rapid Prototyping [1-2] has become a significant icon in today's generation of the manufacturing industry. In some applications it is also called as 3D printing in some applications for its methodology**.** This 3D printing technology is being considered as a new era of manufacturing in the Industry 4.O revolution [3-5].

1.1 Origin of 3-D Printing

Beginning of 3-D Printing innovation was presented by Charles Chuck Hull in the year 1983 at U.S market for Part Prototyping/Rapid Prototyping and accordingly, which throw some light on all the industrial applications such as Aerospace Industry, Automobile Industry, Defense field, Medical & Bio-Engineering, Civil Engineering, Jewelry Industry, GIS applications, Coin Industry, Tableware Industry, Arts & Architecture, Planning & Simulation of complex surgeries, Forensic Science, Anthropology Department and Visualization of Biomolecules, etc. [6-10].

Because of its robust, fast & error-less manufacturing AM plays a vital role in today's manufacturing sector even though it's an expensive process. Added Manufacturing is a fitting name to portray the innovations that assembled 3D components by adding layer-upon-layer material, regardless of whether the material might be Plastic, Metal, Concrete, or even Human Tissues.

2. Elementary of AM

The essential [5] attributes of AM technologies are present in this part. A model is the first or unique illustration of something that has been or will be duplicated or created; it is a model or primer structure. e.g.: A prototype supersonic aircraft [11].

The overall meaning of the model contains three parts of interests:

• Implementation of Prototype; for the whole item itself to its sub-gatherings and segments,

•Form of the model; From virtual model to actual model, and

•Degree of the estimation of the model from an unpleasant portrayal to an accurate replication of the item.

There are three stages of improvement prompting fast prototyping. The principal stage is called manual prototyping, the subsequent stage is known as delicate or virtual prototyping, and the third stage is about quick prototyping. AM is a group of a novel interaction created to make designing models in least lead time dependent on a CAD model of the thing. The customary strategy is machining (tedious). AM permits a part to be made in hours or days as opposed to weeks, given that a PC model of the segment has been produced on a CAD framework.

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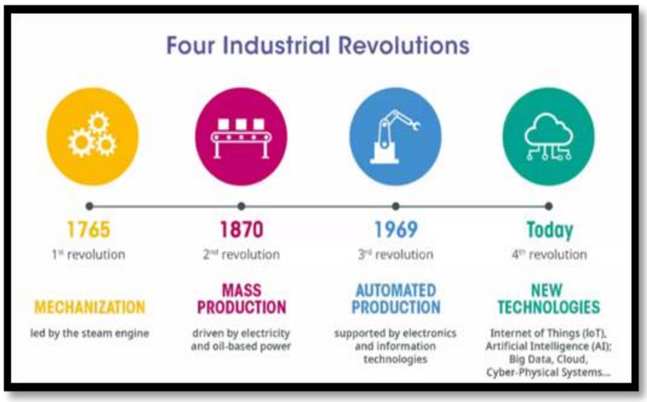

Fig.1: Industrial Revolution's

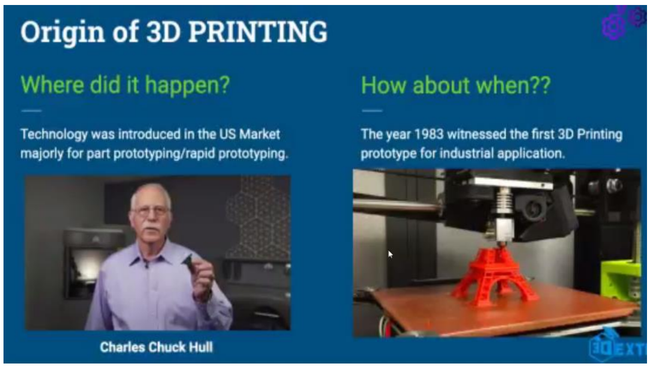

Fig.2: 3DP Origin (Source Courtesy 3DExter Company)

2.1 History of Additive Manufacturing

The improvement of Rapid Prototyping is related with the utilizations of PCs in the manufacturing industries. PCs assume an imperative Design (CAD), Manufacturing (CAM) and Analysis (CAE) fields in which all the enterprises are clubbed up with these most recent innovations.

The historical developments of Additive Manufacturing shown in Table-1.

Table 1: AM / RP technologies (courtesy of Chau C.K et.al. Rapid Prototyping, Principles and applications).

Year of Commencement	Skill Developed
1770	The Mechanization Process
1946	The First Computer
1952	The First NC Machine Tool
1960	The First Commercial Laser
1961	The First Commercial Robot
1963	The First Interactive Graphics System
1988	The First Commercial RP structure

2.2 Why Rapid Prototyping / Additive Manufacturing

The item planners might want to have an actual model/model of another created part or an instead of a PC 3D CAD model. Making a model is a necessary advance of the plan. A virtual model may not be adequate for the architect to imagine the part precisely. The designer able to examine it physically and assess its merits and demerits by studying the RP manufactured prototype. So, using these RP/AM processes we can make our imagination into reality.

2.3 Major Aspects of RP / AM

The four major aspects of AM technology are Input, Method, Material & Applications. Input refers to all the software parameters such as CAD file, Input file format of 3-Dimensional Printing (3DP) file i.e., Standard Tessellation Language (STL) file [2]. Once the STL file is error free, then next step is to print the physical object using the different AM technologies. The other popular formats of file in AM are as AMF, OBJ & 3MF.

The different method of 3DP process is Solid based, Liquid based and Powder based. In this there are several types of methodologies to get the 3D printed part. The material deals with the different Polymer based, Metal based, Ceramic based filaments used for printing the 3D part accordingly.

Applications will assemble different industries into one phase of AM based on the customer availability as shown in the below Figure-3.

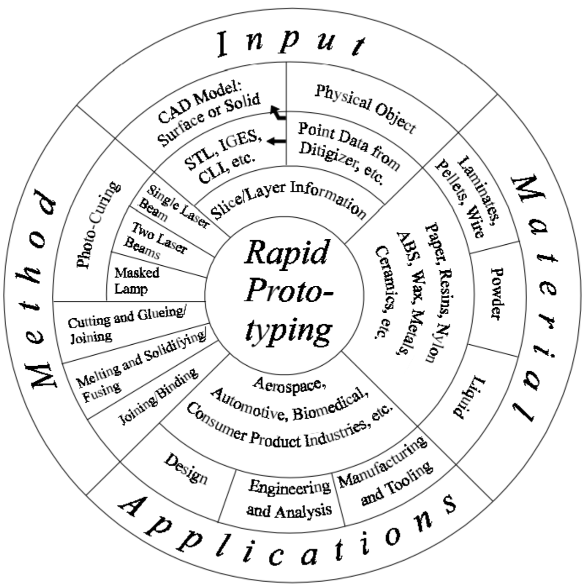

Fig.3: AM Wheel (courtesy Chau C.K et.al. Rapid Prototyping, Principles and applications)

3. Processes of Additive Manufacturing/ Rapid Prototyping

Different Categories, Technologies, Materials, Power source, strengths and weaknesses have been shown in the Table-2. At a glance, all the processes of Additive Manufacturing are discussed accordingly below the table as per its efficiency.

Table 2: Classification of Rapid Prototyping processes (Courtesy Wei Gao et.al. [5])

S. No	Process	Technology	Power Source	Printed Ink
1	Material Extrusion	FDM	Thermal Energy	Thermoplastics, Metals, Ceramics
2	Powder Bed Fusion	SLS / DMLS / SLM / EBM	High Powered Laser Beam / Electron Beam	Polymer, Polyamides, Ceramic Powder
3	Vat Polymerization	SLA	Ultraviolet Laser	Photopolymer, Ceramic
4	Material Jetting	Polyjet/Inkjet	Thermal Energy/Photo curing	Photopolymer, Wax
5	Sheet Lamination	LOM	Laser Beam	Plastic Film
6	Direct Energy Deposition	LENS	Laser Beam	Molten Metal Powder

4. Metal Additive Manufacturing

Metal-based Additive Manufacturing [16] assumes a crucial part in the present shrewd and quick assembling enterprises. It has a prominent role in medical industry, aerospace industry, and defense. Almost all the present medical industries are using metal-based AM, to manufacture implants to reduce the cost. Coming to the Aerospace Industries, GE has done a lot of research on metal-based AM technology [21].

GE uses this technology for developing jet engines and has created history in reducing the material, cost, and fuel consumption rate, since it's a lightweight material without losing its function. Instead of printing hundreds of small parts separately and assembling them together, they are printing all in just two to three parts using this metal-based AM process by saving time, material and cost [19].

There are many metal-based AM processes such as Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Digital Light Processing (DLP), and Laser Engineered Net Shape (LENS) [20]. In which two main processes of Direct Energy Deposition (DED) & Powder Bed Fusion (PBF) process were taken into consideration and elaborated accordingly. For sintering of metal powders, two standard material groups exist such as Direct Metal and Direct Steel [17]. Powder having low dissolving point is liquefied locally and serve after cementing as a fastener for the higher-liquefying segments. In this direct steel process, powder having similar melting point can be sintered straight away.

4.1 Electron Beam Melting (EBM) in Powder Bed Fusion (PBF)

The EBM [6] process was developed by **Arcam AB** (Sweden) in 1997. The principle action in the Electron Beam Melting (EBM) method is to print strong metal parts straightforwardly from metal powder, in light of a 3D CAD model. SLS (Selective Laser Sintering) is similar to the EBM process. This process is relatively new but rapidly developing day-by-day. [2]

- The production chamber is maintained at a high vacuum and high temperature.[14]
- A layer of metal powder is deposited on the fabrication platform. A focused electron beam is used to melt the powder particles in a small volume within the layer.
- The electron beam is scanned to express a 2D slice of the object within the layer. The build table is lowered, and again a new layer of dry powder is put on top of the previous layer.
- In this process, after the removal from the machine, the un-melted powder is cleared off and once again recycled as shown in Figure 4.

The EBM methodology depends on the accompanying two standards [15]:

(i) Prototypes are developed when an electron beam is triggered into the metal powder then the process initiated accordingly [1]. The computer based controlled electron beam in vacuum melts the layer of powder exactly as indicated by the CAD prototype by the getting kinetic energy from the electrons.

(ii) The construction of the prototype is accomplished layer by layer. A layer is added once the past layer has liquefied. Thusly, the strong subtleties are developed of flimsy metal cuts liquefied together.

(iii) In this way EBM process of developing a prototype existed for manufacturing of complex parts which are very much useful for industrial purposes.

4.2 LENS as Direct Energy Deposition (DED) process

LENS is the first Direct Metal rapid prototyping system. It was developed by OPTOMEC [5].

- A strong laser is used to melt the metal powder that which is provided to the focus of the laser beam (ND-YAG) through a deposition head [2].
- These powders are then blown through a nozzle into a melt pool created by a laser beam on the substrate to make a deposited line. Numerous numbers of lines are placed adjacent to each other to make a layer.

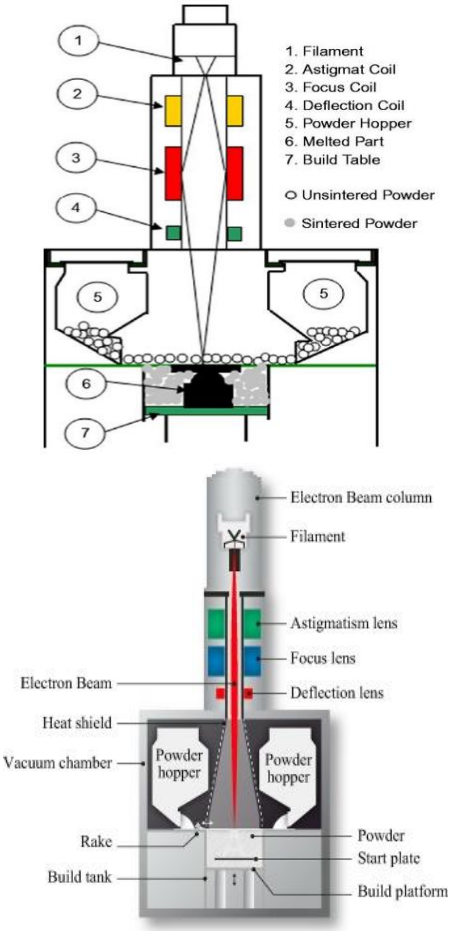

Fig. 4: Electron Beam Melting (Courtesy of Manuela Galati et.al. [14])

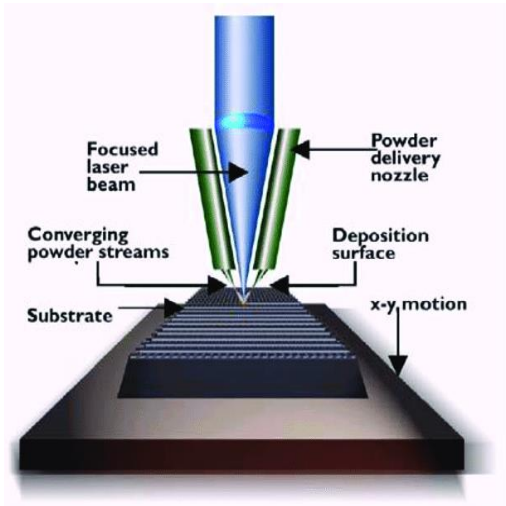

Fig.5: LENS (Courtesy of Manuela Galati et.al. [14])

This type of layer-to-layer making process is repeated until an object is formed. In This process other materials such as tool steel, steel, titanium-based alloy, nickel-based alloy, aluminium, and various ceramics are also used accordingly.

The "LENS" process manufactured products have the strength required to be used as final products, hence the direct metal prototypes may be also be used for product verification and testing or also even in injection moulding tooling systems. In addition to this type of producing parts, they can also be used for repairing the expensive objects such as air craft assemblies that which are initially produced using the traditional methods.

•The following are the LENS process usages: [7]
(1) Building a form and pass on additions.
(2) Fabricating the titanium parts in the industries.
(3) Manufacture titanium related parts for natural supplements.
(4) Producing practically inclination structures.

5. Conclusions

1. The additive manufacturing process is applied to produce near-net-shaped (NNS) products with ease in comparison to the traditional manufacturing process.
2. Complex geometries that cannot be produced by traditional manufacturing can be printed by AM easily.
3. EBM process has better features like high accuracy and strength as compared to LENS process.
4. LENS process is mainly used for more complex parts and less post-processing time as compared to the EBM process.

Though the metal additive manufacturing process giving better and robust manufacturing solutions in the aerospace, defense, and automotive industries, there are still some challenges in this type of metal additive manufacturing such as surface roughness, brittleness of metal 3D printed parts, requires more support structures, Issues like time consumption, size limitations to be eradicated by the new metal AM processes by conducting further research.

Nomenclature

3-D – Three-Dimensional
3DP - Three-Dimensional Printing
3MF – 3D Manufacturing Format
AMF – Additive Manufacturing file Format
AM – Additive Manufacturing
NC – Numerical Control
RP – Rapid Prototyping
RPT - Rapid Prototyping Technology
DMLS – Direct Metal Laser Sintering
DfAM – Design for Additive Manufacturing
LENS – Laser Engineered Net Shaping
EBM -Electron Beam Melting
EBW- Electronic Beam Welding
PBF – Powder Bed Fusion Process
SLM – Selective Laser Melting Process
ND-YAG - Neodymium-Doped Yttrium Aluminum Garnet Laser
DLP – Digital Light Processing
DED – Direct Energy Deposition
GIS – Geographic Information System
GE – General Electric Company
NNS - Near Net Shaped

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