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A Comparison of Additive Manufacturing Technologies

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Abstract

Additive manufacturing (AM) technologies play a very significant role in making metallic/nonmetallic prototypes or products in layered fashion. The main goal of these technologies is to produce fully dense and net shaped metal/non-metal parts in single step. Some additive manufacturing technologies such as Selective Laser Sintering and Laser Engineered Net Shaping are dominating processes while Laminated Object Manufacturing has also been used. This paper tries to present a comparative picture of the different additive manufacturing technologies.
Keywords: Additive manufacturing technologies, Comparative study, Direct metal deposition, laminated object manufacturing, Selective laser melting, Selective laser sintering, Stereolithography

I. Introduction

It is crucial important to reduction of the lead time and cost for the development of new industrial products for the manufacturing industry since time is one of the most important global manufacturing problem[1]. Additive Manufacturing (AM) is one of the best solutions to the manufacturer in which a product is made layer – by – layer. Every layer corresponds to a section of 3D CAD model of the product. AM started with using plastic materials because of ease of process ability and aim of making just visual prototypes. The process has grown to include all types of materials. But it is not successful with ceramics, and also plastics have limited applicability in high – strength applications resulting into faster growth of Additive Manufacturing of metallic products. Today, the biggest chances and efforts are placed in the direct manufacture of long term constant metal parts [2]. The Additive Manufacturing processes for metal can be divided into different categories; Non- Melting, Melting and non-metal components shown in (Fig.1). A further classification can be made on the basis of the used material form; powder, foils or wire.

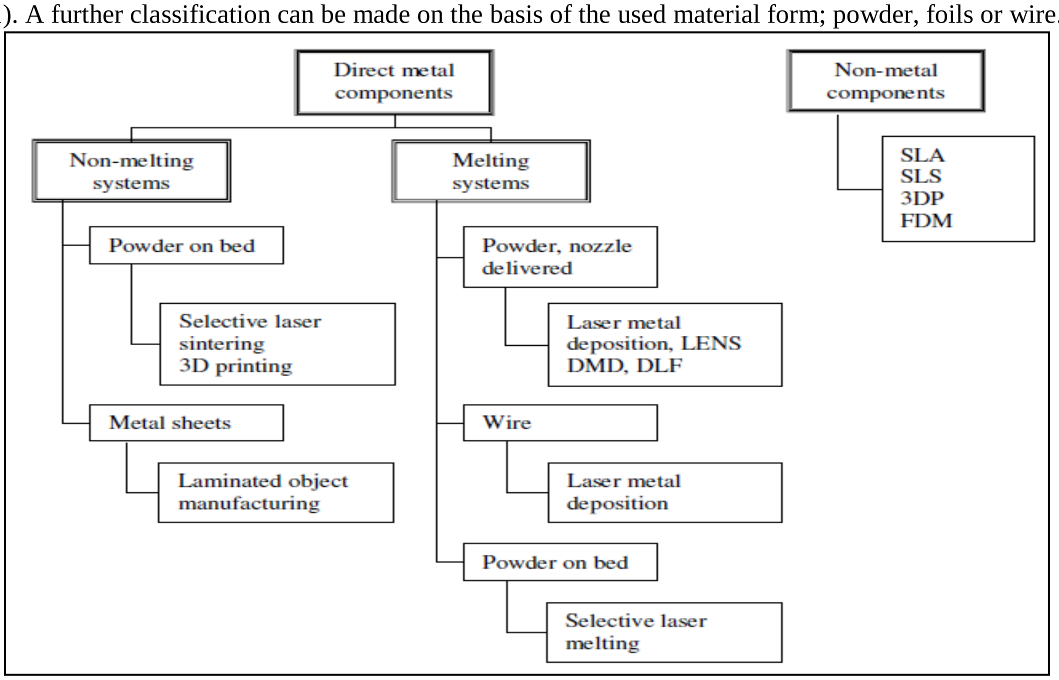

Fig. 1: Classification of additive manufacturing techniques. [3]

II. ADDITIVE MANUFACTURING TECHNOLOGIES

It has been said that the development of AM techniques has been driven by market forces, in which the need to reduce the time-to-market production cycle requires reducing the steps between the design of a component and its manufacture. Additive manufacturing technologies are regarded as a direct link between a digital design of a component in CAD and a physical component, without the need to employ traditional manufacturing processes.

The working principle behind all AM techniques is the layer-by-layer fabrication approach. The initial step in this approach comprises the digital design of a component using CAD software. This digital design is then transformed into a transfer file known as Stereolithography file (STL), in which the surfaces of a solid body are tessellated into triangles. A database of triangle nodes is generated from the face tessellation. This database is mathematically cross-sectioned into small layers comprising a contour and a raster surface. Layer slicing separation is set according to the requirements of a given AM process. Actual part building is made on a layer-by- layer basis. The different contour and raster surfaces are used as patterns to fabricate physical layers which are stacked and bonded on top of each other until a full three- dimensional part is completed [4].

A. Stereolithography:

Stereolithography (SLA) is the pioneer technology in the field of AM. It was first marketed in 1988 [5]

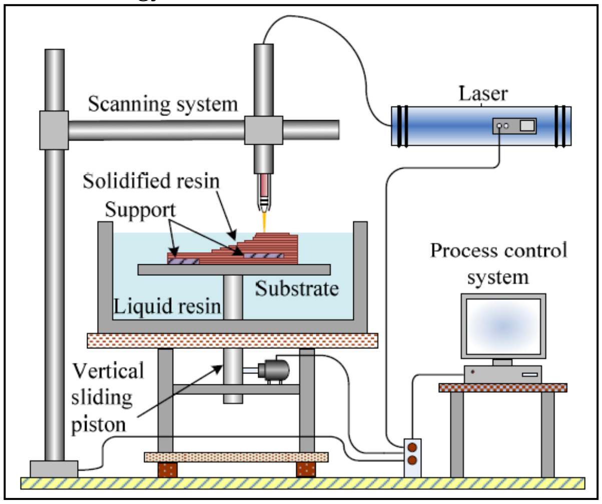

Fig. 2: schematic of stereolithography

A movable platform is submerged in a vat filled with photo- curable resin by a depth corresponding to a layers' thickness. A laser beam guided by galvo scanning mirrors scans over the resin according to a pre-defined pattern, thus producing a layer. The platform is lowered a layer's thickness deep into the vat and the layer fabrication process is repeated with the following layer pattern.

B. Selective Laser Sintering:

The working principle of the SLS process. An even bed of powder is distributed over a movable platform inside a confined chamber. A CO_2 laser beam is scanned over the bed using a galvo-scanning mirror system. The laser beam is absorbed by the powder particles. Their temperature is raised to the sintering temperature, such that particles soften and are able to fuse to each other.

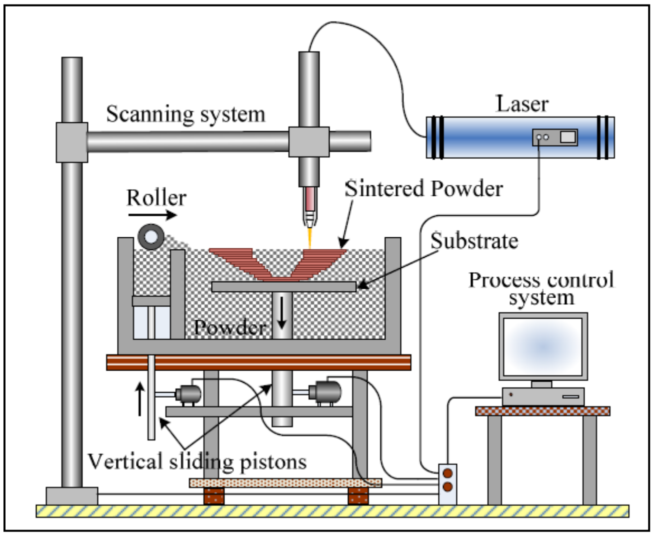

Fig. 3: schematic of laser sintering [6]

C. Selective Laser Melting:

Selective laser melting (SLM) is similar to SLS. In both techniques, a laser beam is used to scan over a bed of powder material which is placed over a piston. After each layer has been processed, the piston is lowered by a layer's thickness and a roller deposits a new layer of powder material. This process is repeated until the component is finished.

D. Laminated Object Manufacturing:

The working principle of the Laminated Object Manufacturing (LOM) process consists of stacking thin sheets of material which are cut according to a layer raster pattern. These layers are assembled and bonded to form a three dimensional component. In principle, any material in sheet form can be used in this process if accompanied by a suitable binding method; one of the simplest combinations is paper layers bonded by glue [5].

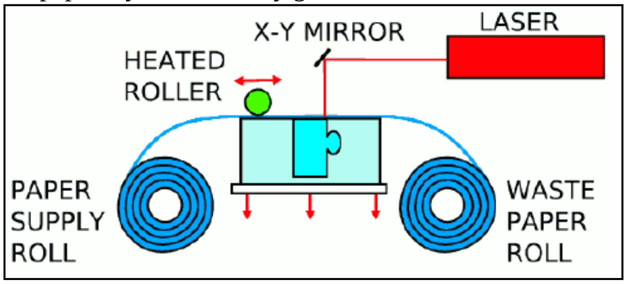

Fig. 4: Laminated object manufacturing

E. Three-Dimensional Printing:

The working principle of 3DP for metal processing is represented in (Fig.5) A bed of powder is dispensed by a roller over a movable platform. A printing head prints the binder over the powder bed to form a layer. The platform is lowered by a layer's thickness and the process is repeated for subsequent layers until the part is completed. The produced component is then heated in a furnace to remove the binder and to induce thermal sintering on the steel particles. After this, the part is infiltrated in a furnace using with a low-viscosity and low melting point material, such as copper.

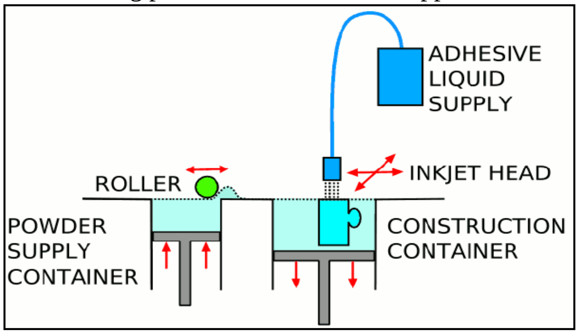

Fig. 5: Three dimensional printing processes

F. Direct Metal Deposition:

Figure 6 illustrates the basic working principle of DMD. A high power laser beam is made to scan over a metal base. As the laser beam generates a small melt pool on the substrate, the powder delivered through a nozzle is melted and fused to the melt pool and bonded to the substrate as a line or track of newly added material. The process continues with the laser scanning according to pre-defined programming of the CNC system or robotic arm without the need for intermediate operations of powder bed dispensing. Overlapping of tracks is used to create a layer, and layer stacking is used to form a three-dimensional shape. There is no definitively agreed name for DMD. It has been known by different names by different companies and research groups, some of which include Laser- Engineered Net Shaping (LENS), from Optomec [7, 8]; laser powder fusion, from Huffman Corporation [9]; Directed Light Fabrication, from Los Alamos National Laboratories, USA [10, 11]; Direct Metal Deposition, from the University of Michigan [12]; laser direct casting, from the University of Liverpool [13]; and by various other names which are described in the literature [13, 14].

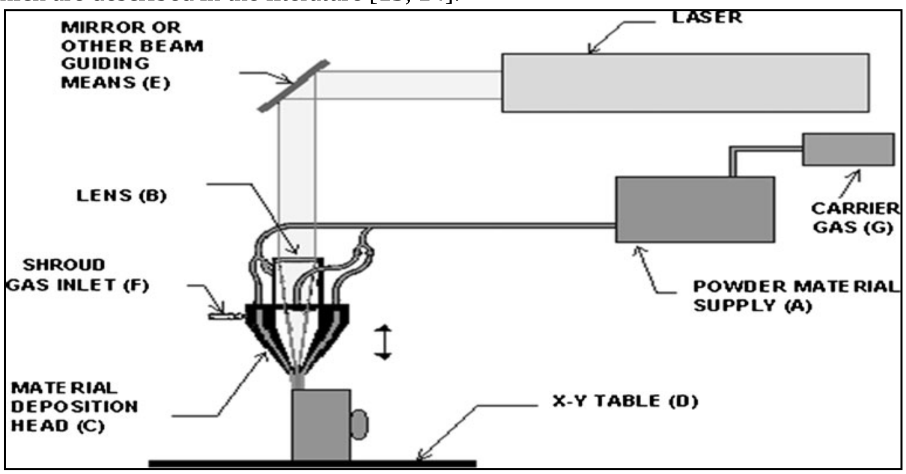

Figure 6: direct metal deposition process.

III. COMPARISON OF SOME PARAMETERS

A. Material Variety:

Table – 1
Materials used in different technologies.

S.No	*Technologies*	*Materials used*
1	*Stereolithography*	*Photocurable resin*
2	*Selective laser sintering*	*Stainless steel,tool steel, plastics, ceramics*
3	*Selective laser melting*	*Steel(stainless steel 316L, hot work steel, tool steel, maraging steel), Titanium CP, titanium based alloy(Ti-6Al-4V,Ti-6Al-7Nb), Inconel 718, Inconel 625,Aluminium based alloys*
4	*Laminated object manufacturing*	*Any material in sheet form*
5	*Three dimensional printing*	*Specially designed stainless steel powder*
6	*Direct metal deposition*	*Titanium(Ti–6Al-4V), stainless steel((316, 304L, 309, 420),tool steel(H13, P20, P21, S7, D2), Nickel based alloys(Inconel 600, 625, 690, 719), Copper and its alloys, Satellite and Tungsten carbide*

B. Surface Quality (Roughness):

Since surface quality is dependent upon type of material and characteristics of powder used, layer thickness and hatch spacing. Good surface quality could be achieved with SLS and SLM, but due to higher laser power used in LENS, it is impossible to get better surface quality. Because as we increase the laser power, the interconnected pores increases and consequently surface roughness increases [15].

Table – 2
Surface finish produced in different technologies.

S.No	*Technologies*	*Surface finish*
1	*Selective laser melting*	*30-60 µm*
2	*Selective laser sintering*	*Rough surface finish*
3	*Direct metal deposition*	*200-300 µinch*

C. Density:

In order to have fully dense parts, the parts produced by SLS are infiltrated with bronze material, as the brown parts have only a 60% dense structure. Also the laser power used in SLS is not enough for sintering of metal powder particles, only binder material is sintered. This also requires furnace sintering process.

On the other side, parts produced by SLM are fully dense because either the laser power used is very high or the laser scan velocity is lower in SLM in contrast to SLS. It is obvious that lower laser scanning velocity increases the effect of the laser beam on the focal zone because laser generation duration time will be higher. This effect also depends on some parameters such as material absorptivity, laser reflectivity and layer thickness [16].

In LENS process, because of high power laser material is completely fused and hence parts produced are fully dense with good metallurgical and thermal properties.

D. Accuracy:

Due to shrinkage, dimensional technologies for RP system have become the vital problem [17]. Shrinkage is dependent on material as well as laser power and sintering condition. In all laser based metal deposition technologies since solidification occurs by thermal operation, shrinkage is inevitable.

In SLS, plastic binder is removed from the part (by firing in a furnace) in order to make the part hard and consequently this additional firing causes the more loss of dimensional accuracy because of shrinkage [17]. In case of LENS, when multi material structure is required, it becomes a crucial factor because shrinkage allowance for different material is different.

Also, accuracy will be affected increasing the interconnected pores with increasing laser power as in roughness. So some post operation should be processed in LENS process to achieve accuracy

E. Advantages and Disadvantages:

Table – 3
Advantages and disadvantages of different technologies.

S.No	*Technologies*	*Advantages*	*Disadvantages*
1.	*Stereolithography*	*Suitable for production of concept prototypes, Fast processing times and Good surface finish and geometrical accuracy*	*Limited to process non-functional materials such as resins or plastics, Resins are cost-expensive and limited in availability, Unable to process functional materials such as metals, Requires support structures,etc.*
2.	*Selective laser sintering*	*Materials which can be processed include plastics, ceramics, sands and some metals, Parts produced are suitable for functional testing and No support structures are required during processing.*	*Availability of metallic materials is narrow; An enclosed chamber is required and Metal sintering leads to porous and mechanically weak components.*
3.	*Selective laser melting*	*Good geometrical accuracy, No support structures are required, Suitable for the processing of metallic materials and Produced components are near fully-dense, suitable for functional use.*	*Size of produced components is limited by the dimensions of the enclosing chamber, Availability of materials is limited, Slow build-up rate and Machining may be required for accurate dimensioning and improving surface finish*
4.	*Laminated object manufacturing*	*Suitable for processing of medium and large sized components, such as dies or metal forming tools and Wide choice of readily available materials in sheet form*	*Poor layer bonding carries the risk of de-lamination, Strength of the produced components in the perpendicular direction to the layers is much less than in other directions and various post processing are required.*
5.	*3-D Printing*	*High productivity, Good geometrical accuracy and no support structures are required*	*Time-consuming post-processing operations are required, Furnace heating is required to eliminate the binder, Sintered part is porous, Mechanical strength of produced components is low and Limited choice of materials*
6.	*Direct metal deposition*	*Layer can be fabricated in any orientation, variety of materials in powder form can be processed, Large components can be manufactured and Higher deposition rates are possible*	*Geometrical accuracy is lower, Stair-stepping effect can limit geometrical accuracy and Post-processing operations may be required*

F. Applications:

The process is useful for making once-off product (spare parts), customized and complex products, low volume production and cheap high-value products (medical implants). There are also certain products which were impossible through conventional means such as mould with conformal cooling channel could be conveniently fabricated. These have found applications notably in the following fields: medical, aerospace, automotive, jewellery and tooling [18-22]. Fig 7 shows the SLM and LENS parts made. LENS give an added advantage of modifying/refurbishment of the surface of the product if it is required in its life-cycle. Besides, the comparison of the powder could be changed from one location to others during processing to make products of varied composition. This could also lead to the possibility of fabrication of Functional Graded Materials (FGM)[23-25].

Fig. 7: SLM steel insert with conformal cooling [26], SLM tool inserts with conformal spiral cooling [27], LENS titanium hip stem[23].

IV. CONCLUSION

Additive manufacturing technologies is an enabling technology for concurrent engineering. Its goal is to reduce product development time, manufacturing costs and lead times, thereby increasing competitiveness. Some additive manufacturing technologies seem to be superior over other while compared against some parameters. DMD process can be seem as future’s technology among additive manufacturing technologies from the point of view such as material variety, multi-material structured part, multi-directional deposition, fully dense in one step. However, some parameters such as surface finish, eliminating secondary finishing operation problems have to be overcome to be succeeded completely

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