Journal of Advances in Science and Technology
Vol. 13, Issue No. 01, (Special Issue) March-2017, ISSN 2230-9659

Additive Manufacturing of Metals: A Review

Sandesh S. Narkhade[1]*, M. G. Rathi[2]

[1]PG Student, Government College of Engineering Aurangbad, Maharashtra, India

[2]Assistant Professor, Government College of Engineering Aurangabad, Maharashtra, India

Abstract – Additive manufacturing technology is making the buzz and is said to entirely change the perspective of how manufacturing will be thought of. Initially used only for prototyping, now AM products can be used as end user items. But for engineering industry, metallic parts still play a huge role and versatility of any technology unable to create metal objects would be severely restricted. So researchers are working to develop technology that is able to create metal parts by additive manufacturing. But cost, cycle time and quality of such parts still pose a challenge for researchers. This paper reviews the technology for metal additive manufacturing in broad sense and is based on various criteria such as materials, raw material form, energy sources etc.

Keywords— Rapid Prototyping, Cycle Time, Materials, Raw Material Form, Energy Source.

---------------------------♦-----------------------------

INTRODUCTION

As the name indicates, Additive Manufacturing (AM) is the technology that creates the parts additively i.e., by adding one layer of material over the other whereas traditional manufacturing technology is subtractive which works by removing the material from block of parent material. The basic requirement of AM technology is CAD model, which then is converted into the format readable by AM machine (generally STL or AMF) and the part can be directly manufactured in the machine. Fig. 1 shows the generalised AM process.

RAPID MANUFACTURING

Rapid prototyping manufactures part by adding one layer of material over the other, but mostly this technology is used for manufacture of prototypes though recent advances have made it capable of producing components which can be used as end user products. But the dream of having additively manufactured parts with remains major problems.

- Excellent quality
- Long life
- Lower cycle time
- Less cost

We can produce parts of any complexity, geometry and materials on CNC machines but on the other hand, if the part of any different material is to be produced, then experimentation and tuning of the AM machine is required. Due to layered manufacturing AM parts inherently exhibit anisotropy, thus the quality of part produced using this technology is poor. Also there is a problem of heat generation and thus distortion and cracking of AM parts. The parts produced on CNC machines have very short cycle time as compared to parts manufactured using AM. So these limitations are needed to be overcome and research must be focused in this direction.

Broadly speaking, metal AM technology can be classified as below

- Laminated Manufacturing
- Powder Bed Technologies
- Deposition Technology
- Hybrid Technology

CNC machining can also be categorized under RM technology but the major difference between CNC machining and other technologies enlisted above is CNC is purely subtractive technology while others are additive technologies. The brief review of each of these technologies is discussed next.

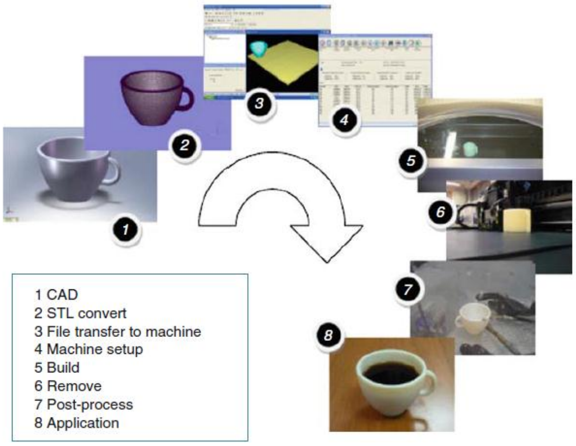

Fig. 1 Generic AM process [1]

A. CNC machining

CNC is specialised and versatile form of soft automation and its applications cover many kinds, although it was initially developed to control the motion and operation of machine tools. There are 3 main facet of CNC machining enlisted below

1. Machine tool
2. Cutting tool
3. CAM software

Despite of huge development in IT field, CAM software still remains the major area of improvement in CNC technology. Not only the path of NC program be correct and optimal but its cutting parameters too (spindle speed and feed rate) must be safe and optimal. The cutting parameters are specified only once in the program and hence may not be optimal throughout due varying radial and axial depths of cut.

Further there will be variation in the machining forces due to various factors such as geometry. So cutting parameters specified at very beginning will not be optimal as they do not take into account this variation of forces during machining. So, adaptive control must be applied in CAM software, which changes the machining parameters online by learning about the machining forces and other varying factors. But such adaptive control systems available currently lack robustness and are very costly.

B. Powder bed process

In powder bed based AM technologies each layer is created by joining the powder particles with the source of energy such as laser or jet of a binder. Then fresh layer of powder is spread on the already created layer and process is repeated till the complete part is obtained.

1) Laser based powder bed process

Laser based powder bed process consists of laser as a source of energy for melting the metal powder particles. There are 2 approaches adopted by laser based metal powder process, viz., binder coated powder approach and plain powder approach. In the binder coated powder approach metallic powder particles are coated with a polymeric binder so that low laser power is able to melt it. Laser power about 60W is sufficient to melt the polymeric binder and form the green part which further is sintered in the high power based laser to form product suitable for end use. In the second approach a plane metallic powder is melted with the high laser power. Laser power is as high as 200W. Part directly suitable for end use is obtained with this process.

2) Electron beam based powder bed process

As the name indicates, electron beam is used as energy source to melt the metallic powder. Most of the machines use Laser as energy source because of its high accuracy but electron beam as its own advantages, viz., higher energy efficiency (15-25% as against 2-5% of laser beam). The only problem with electron beam as energy source is that it requires high vacuum environment for its operation.

3) Arc based powder bed process

It is in principle possible to replace laser or EB by the arc created by torch of metal or tungsten inert gas welding, e.g. it is possible to make metal torch traverse a path over a paste of material applied over a substrate in order to harden the layer of paste.

4) Binder based powder bed process

Binder based powder bed process uses the binder material to fuse the component material particles together. One of the processes using this principle is 3D printing invented at MIT USA. 3D printing is more versatile than above mentioned AM processes since it can be used to deposit different material particles when impinging jet of binder on powder, so alloying could be taken care of. But the particle resulting from this initial binding process is green which lacks in strength. So sintering follows to impart strength to part and ensure proper bonding between metal particles.

C. Laminated Object Manufacturing (LOM)

As the name indicates LOM method utilises the lamination process to make the component.

Journal of Advances in Science and Technology
Vol. 13, Issue No. 01, (Special Issue) March-2017, ISSN 2230-9659

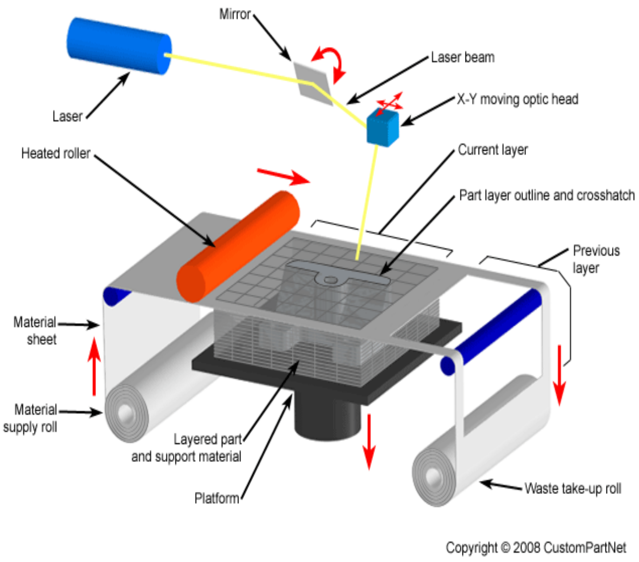

Fig. 2 Schematic of LOM

LOM does not use the conventional wisdom of cut and paste but instead it uses the principle of paste and cut. A sheet of metal is glued/ laminated to the substrate first and is then cut using laser to required profile. Layer after layer is built in this way to make the final part.

D. Deposition Process:

Deposition process follows the principles of extrusion process in which the object is formed by depositing the molten material through the nozzle in the required profile and it is allowed to be solidified. FDM is popular process for non metallic objects. In case of metals this concept is extended to weld deposition. The weld deposition may be done using arc welding, EB welding or laser welding.

1) Laser based deposition process:

In laser based deposition process, the laser is the central part of the deposition nozzle around which other nozzles containing metal powder are mounted. Laser creates a weld pool on the substrate layer in which powder particles from surrounding nozzles dive into create a layer of the component. It is called as Laser Engineered Net Shaping or LENS. It produces near net shaped objects. The path for Laser head is to be manipulated by operator so again CAM software has a role to play. LENS builds part vertically and hence does not use any inherent support structure.

The major problem in laser based weld deposition system is that of laser and powder efficiency. Laser efficiency is as small as 2-5% [2] whereas powder efficiency is in the range of 10-15%. Slow deposition rate is also a drawback of this process.

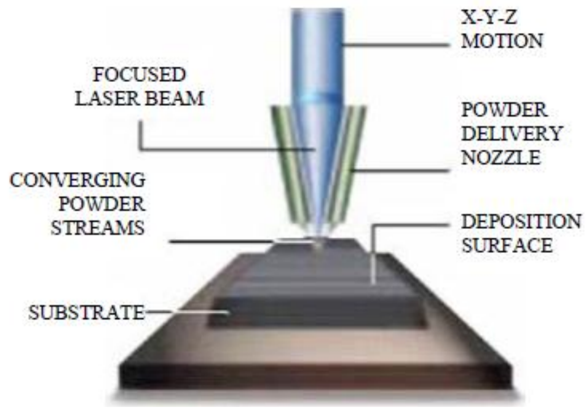

Fig. 3 Schematic of LENS

Direct Metal Deposition (DMD) developed at Michigan University, USA and marketed through Precision Optical Manufacturing, Inc. (POM) uses optical feedback to ensure the integrity of deposition.

2) Arc based deposition process

Arc based deposition process is similar to laser deposition process in that LENS. The only difference being the Laser source is replaced by plasma arc. Many researchers tried to incorporate principles of welding to produce metallic AM part but major breakthrough was encountered in PDM (Plasma Deposition Manufacturing)

E. Hybrid Processes

Hybrid RM processes, as the name indicates use hybrid approach for manufacturing the part. As in case of LENS, powder deposition and subsequent sintering is used, hybrid approach makes use of CNC machine tools in stage after deposition to obtain desired surface finish. Thus this kind of technology enables us to use thick layers deposition in one pass so as to obtain desired geometry quickly. Surface finish factor is taken care of in next stage of machining by CNC. Geometric integrity is the concern of layered deposition and required surface finish is generated by subsequent operation on CNC. 3 types of hybrid processes which are enlisted below-

1. Hybrid RM using laminated manufacturing and CNC machining.

2. Hybrid RM using powder-bed technology and CNC machining.

3 Hybrid RM using deposition technology and CNC machining.

Out of above processes, laminated hybrid manufacturing process is discussed in brief.

1) Hybrid Rapid manufacturing using CNC machining

Ultrasonic additive manufacturing (UAM) is a solid freeform fabrication process also known as Ultrasonic Consolidation (UC). It is a hybrid sheet lamination process that utilizes ultrasonic seam welding to merge metallic tapes [1,2,3] combined with computer numerically controlled (CNC) milling for dimensional accuracy.

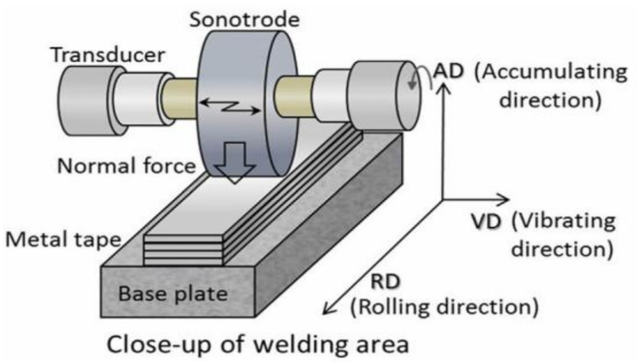

Fig. 4 Schematic of UAM

Step1: Ultrasonic seam welding

During UAM, a rotating sonotrode travels along the length of a thin metal foil (typically 100–150µm thick). The foil is held closely in contact with the base plate or previous layer by applying a normal force via the rotating sonotrode. The sonotrode oscillates transversely to the direction of motion, at a constant 20 kHz frequency and user-set oscillation amplitude. This procedure is repeated until a complete layer is placed. The next layer is bonded to the previously deposited layer using the same procedure.

Step2: CNC milling

Typically four layers of deposited metal foils are termed one level in UAM. After deposition of one level, the CNC milling head shapes the deposited foils/layers to their slice contour (the contour does not need to be vertical, but can be a curved or angled surface, based on the local part geometry).

Low surface roughness and high dimensional accuracy CNC machining eliminates the stair-stepping effects found in other AM processes. The final products show low surface roughness and high dimensional accuracy that is independent of the foils layer thickness.

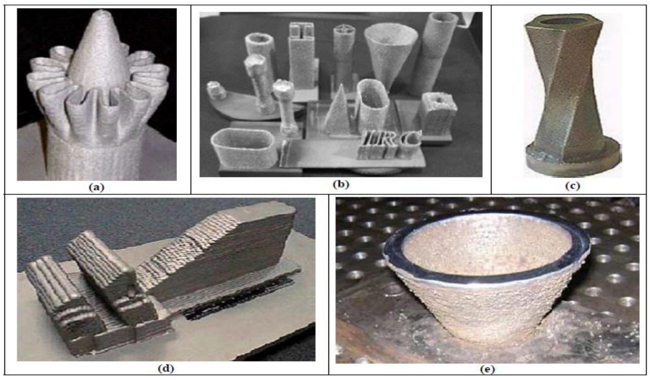

Fig. 5 Comparison of surface quality of RM processes using Laser, EB and Arc sources

Notes: (a) LENS, (b) Laser, (c) EB, (d) LAM-Laser, (e) HLM- Arc

CLASSIFICATION OF RM PROCESS

Broadly speaking, RM processes are classified based on the criterions enlisted below which are discussed in subsequent sections [2].

- Material
- Material Matrix
- Form of raw material
- Applications

A. Classification based on material

RM processes can be classified based on materials in 3 subgroups enlisted below

1. Polymeric
2. Ceramic
3. Metallic

Polymeric materials have very wide applications as mechanical industry is shifting from metal parts to polymer based parts gradually. Ceramic parts are generally used for applications such as mould making whereas vast application still lies with metal additive manufacturing.

B. Classification based on metal matrix

AM processes can be classified into 3 groups based on metal matrix as under,

1. Monolithic
2. Composite

3. Gradient

Monolithic has very uniform matrix throughout resulting in uniform properties, composition and structure. Gradient and composite objects are opposite. The composite objects have discrete jumps in gradient rather than the smooth transitions typical of the gradient objects.

Realising gradient and composite materials have been hard till recently for want of suitable design and manufacturing tools.

RP has made the manufacture of these objects feasible by exploiting its inherent inhomogeneity. However, their use is limited by the lack of design tools capable of representing the interior of the objects. Existing CAD packages define only the boundary assuming a homogeneous interior. These boundary definitions are being augmented with volumetric definitions to solve this lacuna.

C. Classification based on the raw material form

The form of the raw material too dictates a classification. The most popular forms are solid materials in the form of filament, sheet or powder and liquid materials. As it can be spread to any thickness, liquid raw material is used in very accurate processes including micro-manufacturing. Such accurate processes more often use photo-polymer liquid in conjunction with a sophisticated laser. Other liquid raw materials reported are molten wax and water (Liu et al., 2002). Powder form is popular when it comes to material variety as any two materials can be mixed in this form irrespective of their alloying characteristics.

Powder-based RM processes like SLS, 3DP; LENS, etc. cater to a variety of materials. Fused Deposition Modelling (FDM) is a popular process that uses extrusion of plastic filament. Sheet or laminate form was first used in Helisys's LOM which produced wood-like prototypes/ patterns out of paper.

SELECTION OF RM PROCESS

All RP processes achieved total automation through the unique strategy of building the object in layers but this approach also became the root cause of its problems, particularly of quality. Therefore, RM has to adopt a variety of multi-faceted and hybrid approaches. As described in the previous section, these were earlier classified into 5 major groups each having further sub-divisions. When a component is to be produced, one has to choose the appropriate RM process among these myriad technologies. This section attempts to give some guidelines for such a selection. Some of these rules are:

- Powder-based processes are suitable when material variety is required.
- EB RM is suitable process for Ti alloys.
- Powder-bed technology is suitable for complex shapes.
- Deposition technology with multiple powder nozzles is suitable for gradient objects.

Capabilities of RM processes are given under seven groups, namely, general, geometric, metallurgical, mechanical, thermal, energy and cost and time. Details like the possible applications and technology used are the general characteristics. The geometric characteristics are the complexity, maximum size of the part that can be built, the size of the smallest feature, layer thickness, accuracy and surface finish. Although there are a number of metallurgical, mechanical and thermal characteristics, only the most important are included. Cost and time characteristics will help in sorting the feasible processes. These implicitly consider energy. Some of the properties can be improved through post processing. For instance, shot blasting may improve the surface finish and heat treatment may improve the strength. Such improvements are specified in brackets.

The selection of the most suitable RM process for a given component can be done more objectively by first listing down its requirements in the same order and looking for the best matching process in Tables VI and VII. The geometric, metallurgical, mechanical and thermal characteristics strongly influence the selection process. The energy and general characteristics do not directly influence the selection. When

Multiple RM processes meet these four requirements; these can be presented to the user in the order of the cost or time. On the other hand, no RM process may be selected due to its stringent quality requirement. If so, the software will select a few RM processes in the order of their closeness to the requirements highlighting the specifications that were not met along with the extent of their respective deviations. Such a feedback will help in revising the design so as to relax those specifications. In other words, this database or the selection software will be a tool for Design for Rapid Manufacture (DFRM).

The selection software can then scans through the database and identify the RM processes that meet the requirements. As each characteristic is fuzzy and influence the selection to varying extents, the selection software may have to use fuzzy logic.

CONCLUSION

Rapid prototyping is evolved into rapid manufacturing. This evolution is tedious process and is never ending as technology develops and time passes. Various optimizations are but to follow in the coming times and 3 bottlenecks mentioned in this paper, viz., quality, cycle time and cost will be minimized so as to make technology more versatile and useable.

This paper, in brief, overlooks the various processes that are currently commercialised and available to user particularly in metal additive manufacturing. Further it classifies AM process based on various criteria and segregates the processes based on various factors. This will be useful for getting the first-hand account of the technologies based on the parameters discussed in this paper.

REFERENCES

[1] I. Rosen, D.W. Gibson, B. Stucker (2010), "Additive Manufacturing Technologies Rapid prototyping to Direct Digital Manufacturing" 10th Edition, Springer

[2] K.P. Karunakaran et. al., "Rapid Manufacturing of Metallic Objects", Rapid Prototyping Journal, 18/4 (2012) 264–280

[3] Inside Metal Additive manufacturing, 2014-2016, available http://www.insidemetaladditivemanufacturing.com/blog/ultrasonic-additive-manufacturing

[4] Harrysson, O.L., Cansizoglu, O., Marcellin-Little, D.J., Cormier, D.R. and West, H.A. II (2008), "Direct metal fabrication of titanium implants with tailored materials and mechanical properties using electron beam melting technology", Materials Science and Engineering: C, Vol. 28 No. 3, pp. 366-73

[5] Himmer, T., Nakagawa, T. and Anzai, M. (1999), "Lamination of metal sheets", Computers in Industry, Vol. 39 No. 1, pp. 27-33..

[6] Janaki Ram, G., Yang, Y. and Stucker, B. (2007), "Effect of process parameters on bond formation during ultrasonic consolidation of aluminum alloy 3003", Journal of Manufacturing Systems, Vol. 25 No. 3, pp. 221-38.

[7] Karunakaran, K.P. and Shringi, R. (2008), "A solid model based off-line adaptive controller for feed rate scheduling for milling process", Journal of Materials Processing Technology, Vol. 204 Nos 1/3, pp. 384-96

[8] Xinhong, X., Haiou, Z., Guilan, W. and Guoxian, W. (2010), "Hybrid plasma deposition and milling for an aeroengine double helix integral impeller made of superalloy", Robotics & Computer-Integrated Manufacturing, Vol. 26 No. 4, pp. 291-5.

[9] Zhang, H., Xu, J. and Wang, G. (2002), "Fundamental study on plasma deposition manufacturing", Surface and Coatings Technology, Vol. 171 Nos 1-3, pp. 112-18.

Corresponding Author

Sandesh S. Narkhade*

PG Student Government College of Engineering Aurangbad, Maharashtra, India

E-Mail – narkhade.sandesh@gmail.com