ADDITIVE MANUFACTURING – PROCESS, APPLICATIONS AND CHALLENGES

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All manufacturing processes can be broadly classified in four major groups viz forming, joining, subtracting manufacturing and additive manufacturing (AM) processes. In AM processes the desired shape and size is obtained by deposition of layers contoured in x-y plane and the third dimension z results from single layers being stacked up on top of each other. Rapid prototyping was one of the earliest additive variant, and its mission was to reduce the lead time and cost of prototypes of new products. With time and technology advancement, additive methods are moving further towards the manufacturing end. This paper gives an overview to basic AM process, applications in various fields and challenges associated with it.

Key words : *Additive manufacturing, Rapid prototyping, Stair Case Effect, Part orientation, Build time*

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1. INTRODUCTION

Each product that is used by us is made through a manufacturing process. Manufacturing can be simply defined as value addition processes by which raw materials of low utility and value due to its inadequate material properties and poor or irregular size, shape and finish are converted into high utility and valued products with definite dimensions, forms and finish imparting some functional ability [1]. It is very difficult to count the exact number of various manufacturing processes existing and is being practiced presently because a spectacularly large number of processes have been developed till now and the number is still increasing with the gro wing demands and rapid progress in science and technology. However, all such manufacturing processes can be broadly classified in four major groups viz forming, joining, subtracting manufacturing and additive manufacturing (AM) processes. In subtractive manufacturing processes the desired shape and size is obtained from work material by subtracting or removing the undesired material by suitable method. All conventional and non-conventional machining processes are subtractive manufacturing processes.

In additive manufacturing processes the desired shape and size is obtained by deposition of layers contoured in x-y plane and the third dimension z results from single layers being stacked up on top of each other. All additive manufacturing processes are also known by the names rapid prototyping (RP), additive fabrication, digital manufacturing, three dimensional printing, rapid manufacturing, solid freeform fabrication (SFF) and layered manufacturing. If this process occurs in the R&D stage, it is called rapid prototyping [2 cited by 3]. Rapid prototyping is a group of modern manufacturing technologies that are used to produce three-dimensional prototypes from CAD representations [4]. In addition to prototypes, RP techniques can also be used to make tooling (referred to as rapid tooling) and even for production of quality parts (rapid manufacturing) [5].

Additive manufacturing started in the late 80's with Stereolithography[6]. Since then, many new ideas have come up, many patents have been deposited, new processes were invented and commercialized, some of which have already disappeared. An overview is given in Table 1.

Table 1. LM technologies, acronyms and development years [6]

Name	Acronym	Development years
Stereolithography	SLA	1986-1988
Solid Ground Curing *	SGC	1986-1988
Laminated Object Manufacturing	LOM	1985-1991
Fused Deposition Modeling	FDM	1988-1991
Selective Laser Sintering	SLS	1987-1992
3D Printing (Drop on Bed)	3DP	1985-1997

*SGC disappeared in 1999

Rapid prototyping was one of the earliest additive variant, and its mission was to reduce the lead time and cost of prototypes of new products, which was done with subtractive tool room methods. However, with time and technology advancement, additive methods are moving further towards the manufacturing end.

2. ADDITIVE MANUFACTURING PROCESSES

In contrast to traditional subtractive manufacturing techniques like milling or turning or formative processes like casting or forging, additive processes shape the part by adding material. This is mostly done layer by layer, even if the layer itself is composed of discrete volumes. The basic steps involved in the process are as below.

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

According to Kruth [7], the material addition processes may be divided by the state of the manufacturing material before part formation.

1. Liquid-based processes
2. Powder-based processes
3. Solid-based processes

The liquid-based technologies may entail the solidification of a resin on contact with a laser, the solidification of an electro-setting fluid, or the melting and subsequent solidification of the material. The processes using powders compound them either with a laser or by the selective application of binding agents. Those processes which use solid sheets may be classified according to whether the sheets are bonded with a laser or with an adhesive.

Additive manufacturing processes according to state of aggregation of their original material and is given in fig 1.

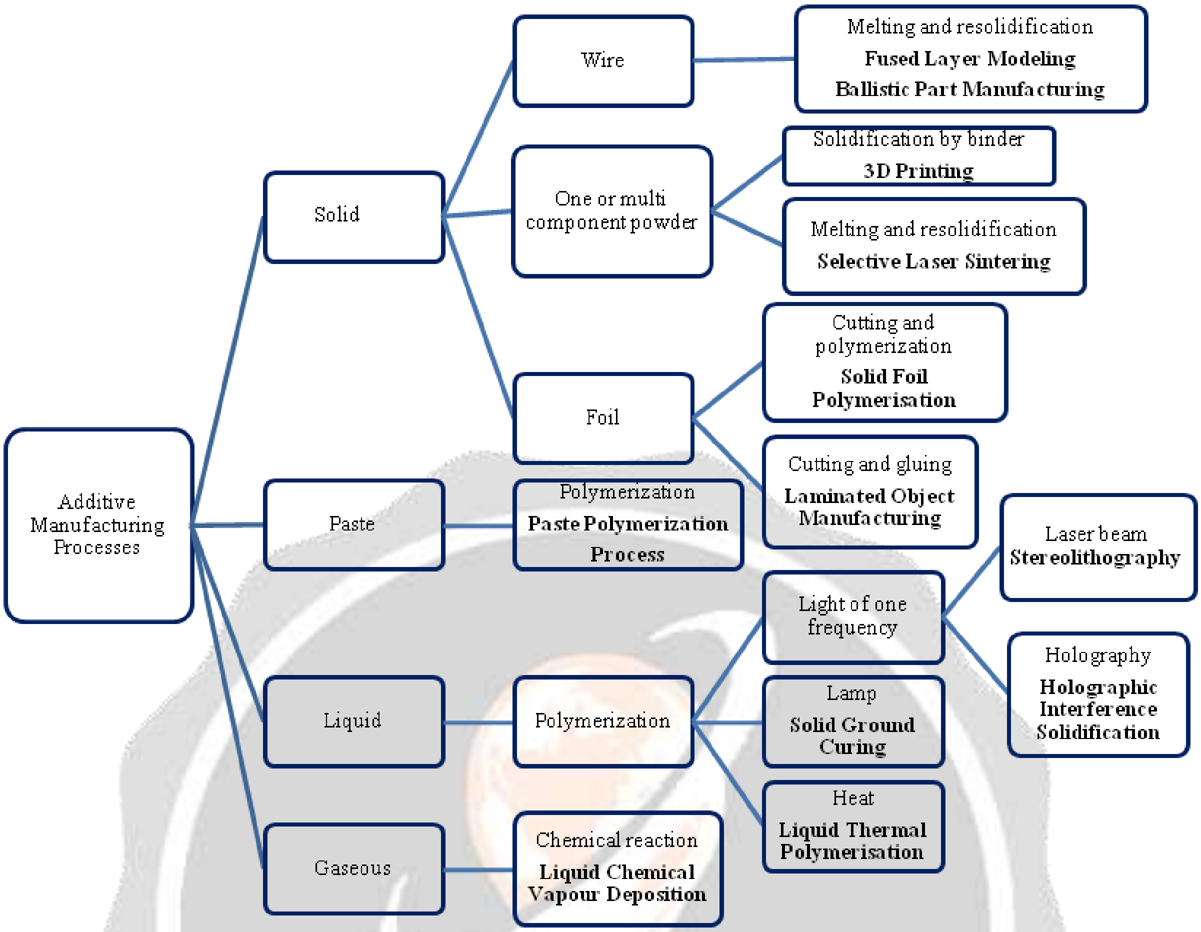

Fig. 1 Classification of AM Processes [8]

3. APPLICATIONS OF ADDITIVE MANUFACTURING PROCESSES

An increasing advantage of the technologies, AM is progressively pushed from Rapid Prototyping towards small series production. Today, Additive manufacturing is widely used for a variety of applications in many different fields such as prototyping, direct and indirect tooling, end product manufacturing, Medical, Architecture, defense, aerospace, electronics, automobile, etc. Even, consumer industries such as the sports, the furniture or the jewelry industry are becoming aware of the advantages of AM-technologies for their business. The main applications of the AM reported are as follows.

3.1 Functional prototype

The first and foremost use of additive manufacturing is for built up the prototypes. A prototype is an important and vital part of the product development process. The saying “a picture is worth a thousand words” can be updated to “a prototype is worth a thousand pictures” [9]. Better materials have enlarged the scope of prototypes that can be produced by additive manufacturing techniques from visual or look-at prototypes to more functional prototypes [10].

3.2 Tooling

Additive manufacturing technologies are widely used in injection moulding and metal casting industries for a new mould design and manufacturing. It refers to directly create moulds with different types of AM techniques, and then required mechanical properties, dimensional accuracy, and surface quality is attained with necessary postprocessing and machining. Direct metal laser sintering (DMLS) is a material addition process suitably used for the manufacturing of moulds for die casting [11]. The metal die for automobile deck part of high quality and low cost with short cycle is produced by large scale LOM equipment SSM-1600 [12]. Rapid tooling offers an effective method to make mould, and shows a high potential for the reduction of time and cost [13]. The casting die for clutch house of diesel engine prepared by laminated object manufacturing technology has satisfactory lifetime and was successfully used in 100 rough castings of clutch house for diesel engine [14].

3.3 Functional Product

With the advent of new materials and improved properties additive manufacturing is also used to produce parts that are used as final product. A rapid prototyping process called Multiphase Jet Solidification (MJS) was used for direct manufacturing of metallic components [15]. Layer manufacturing technology has the potential to become a manufacturing system capable of direct fabrication of objects in metal in an economical manner [16]. A rapid prototype casting process was successfully developed by combining SL with gelcasting, which provided a sample and valid rapid prototyping to fabricate turbine blades with abnormal film cooling holes [17]. Additive manufacturing processes was also used for manufacturing of custom tailored shoes [18]. A cost effective rapid manufacturing processes have been proposed to produce high integrity aerospace components in production volumes [19]. Components including propellers and the hull structure of a meso-scale underwater vehicle were fabricated by the Shape Deposition Manufacturing process [20].

3.4 Medical

Capability to build uniquely shaped products with complex geometry attracted additive manufacturing in medical applications also. Techniques such as computer-aided-tomography (CAT) and magnetic resonance imaging (MRI) are widely used in medicine, and their associated data processing systems are now capable of turning 2D image slices into 3D image display [9]. Such computer images can be used to assist medical practitioners in a number of areas, particularly diagnosis and surgical planning. Latest studies have identified silk fibroin (SF) protein as a suitable material for the application of additive manufacturing technology. Using the indirect RP method, via the use of a mould, SF tissue scaffolds with both macro- and micro-morphological features can be produced and qualitatively examined by spectral-domain optical coherence tomography [21]. Other applications of 3-D photography and metal spraying technology have been reported to manufacture patient-specific models (lead masks) and protective shields in cancer treatment [22].

4. CHALLENGES TO ADDITIVE MANUFACTURING

In additive manufacturing objects are manufactured as a series of horizontal layers poses a unique set of problems irrespective of the techniques involved in the fabrication of each layer. Some of these problems are technical and may be as a result of hardware limitations while other may be due to the finishing operations. This section provides some insight into the considerations that must be made when building parts by additive manufacturing techniques.

4.1 Stair Case Effect

Through AM process part is manufactured layer by layer, the boundary of the part is a stepped approximation of the boundary of the progenitor CAD model. As a result of this, all parts manufactured by AM processes exhibit a staircase effect [23].

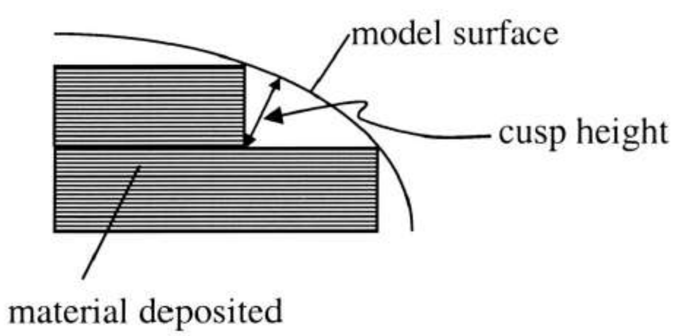

Fig.2 Evaluation of staircase by cusp height [24]

The error associated with the staircase effect can be quantified by considering the cusp height. The cusp height is the maximum distance measured along a surface normal, between the model surface and the layer. Uniform slicing results in an increase in the build time (if many thin layers) or a poor surface finish (if fewer thick layers) [24]. A balance between the surface finish and build time is achieved by adaptive slicing. In adaptive slicing the layer thickness is variable according to the geometric features of the model. Stair case effect can also be eliminated by directly depositing 3D layers by changing the layer thickness along the tool path within one layer to fit the slicing. Directly depositing 3D layers not only eliminates the staircase effect but also improves manufacturing efficiency by shortening the deposition and machining times [25].

4.2 Layer Thickness

The thickness of layers is also important parameter as it directly affects the errors due to staircase effect as discussed in previous paragraph. Minimum cusp height can be obtained using the smallest possible layer thickness that can be physically created by the system, but the smaller the layer thickness, the more slices are required resulting in longer data processing time, larger data files and a longer build time. To optimize the process, variable layer thickness may be used over different ranges of the part called adaptive slicing.

4.3 Deviation from CAD geometry

During AM process a CAD is converted to standard tessellation language (STL) format (as machine input), the outer surface of the part is estimated to some triangles and this estimation causes error, especially around the points with higher curvature (lower radius). The error can be minimized by meshing with smaller triangles. However, it requires more time to process the file and a more complicated trajectory for laser.

4.4 Build Time and Part orientation

The build time for fabrication of any part is mainly dependent on the number of layers involved, and may therefore be minimized through careful selection of the part orientation. However it is not simply a matter of choosing the orientation with the smaller Z height because all the other effects discussed must also be considered, and a compromise must be made. In many layered manufacturing systems the degree of part distortion occurring as a result of the layer generation process is department on the orientation of the part with respect to the slice axis [9]. A geometric algorithms were proposed for the determination of good fabrication orientations considering various factors such as surface quality, build time, volumetric error based on stair case, part cost and support structure [26-29].

5. CONCLUSION

AM is one of the fastest growing new technologies of manufacturing. Through this technology products are manufactured using automated machine by adding the material in layer by layer and directly from the 3D CAD model. AM processes are used in various fields. This paper provides a platform for researchers, new learners and product manufacturers to create an awareness of Additive manufacturing technology for creating the complicated and different contour products in various fields of applications. The various points are discussed in this paper for the researchers to insight the challenges associate with additive manufacturing.

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