A REVIEW ON DIRECT METAL LASER SINTERING

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Abstract: Additive Manufacturing (AM) is the process of producing 3 dimensional objects directly from CAD data and basically works on the principle of layer manufacturing. Additive Manufacturing was used primarily to produce prototypes but with the advancements made, it is finding application in the production of functional end products. One of the few Additive Manufacturing methods that has garnered interest in recent times is the Direct Metal Laser Sintering Process (DMLS). In Direct Metal Laser Sintering a thin layer of atomized metallic powders is evenly distributed by a coating mechanism on a substrate plate and a high intensity laser is employed to fuse or sinter the powders to form a solid layer, which is repeated till the final product is obtained. DMLS is a fast developing process being utilized for material science and in the industrial sector. The ability of DMLS to produce accurate, functional products with intricate designs in a single fabrication step, custom properties can be achieved by controlling the process parameters in DMLS and there is a considerable reduction in the material wastage and more freedom in designing, all these make DMLS a promising option for many manufacturing and industrial challenges. A detailed literature review on the Process of Direct Metal Laser Sintering (DMLS) is done in this paper.
Keywords: *Additive Manufacturing, Direct Metal Laser Sintering*

1. INTRODUCTION

Additive Manufacturing is a manufacturing technique in which physical 3 dimensional objects are directly produced from a CAD model. Additive manufacturing is accomplished by deposition, joining or solidification of the desired material, which can be epoxy resins, silicon, various types of plastics, polycarbonates, metal alloy powders, etc. The roots of additive manufacturing can be traced back to topography and photosculpture. Topography is the process of mould making by stacking a number of wax plates and cutting each one along the contour lines and Photosculpture is a technique of creating replicas by photographing the object simultaneously with 24 equally spaced cameras and using the silhouette of each photographs to be model 1/24th of the object. Over the years various Additive Manufacturing methods have been developed which employ the processes like polymerization, photomasking, extrusion process, printing and laser cutting, to fabricate the desired object. Additive Manufacturing decreases development time of the product, allows for changes to be made before it becomes a costly affair, helps in producing one-off intricate objects and complex features with relative ease which gives it a upper hand over conventional manufacturing. Additive Manufacturing was mainly used for the manufacture of prototypes used for visualization and demonstration because of inaccuracies and limited range of usable materials, and the end products of these prototypes were manufactured conventionally. This changed as advancements in Additive Manufacturing allowed for the production of more accurate prototypes made of a wide range of materials which can be directly used functionally. Additive Manufacturing can be used in the design phase planning, experimenting and addressing any issues with the design in a physical sense. It is used for testing and validating ideas relating to product development. Additive Manufacturing can produce prototypes at a faster rate which is used to visualize the product, which in turn helps in effectively communicating and demonstrating ideas. It also helps in scheduling the product development process and is used as markers for the end of various phases of the product development process [1,2,3,6,8].

The Additive Manufacturing process which is used to produce metal products is Direct Metal Laser Sintering (DMLS). Direct Metal Laser Sintering employs the process of sintering or fusing fine metal alloy powders with a high intensity laser. This method can be used to build objects in almost any metal alloy by sintering which means that the particles are fused together by the heat which is not sufficient to melt the metal powder. The major advantage of DMLS is that the products produced using DMLS are mostly free of residual stresses and internal defects which are prevalent in traditionally manufactured metal components. Desired properties can be attained in the product by controlling the process parameters of DMLS and there is a drastic reduction in material wastage as the left over powders in the build chamber can be reused. DMLS also provides the freedom to design intricate features and cavities and also reduces the number of separate parts to be built and assembled for a particular product, which in the long run reduces the complexity of the production of that product. One of the major drawbacks of DMLS is that it is quite expensive which limits it's use to only certain projects [4,5]. Figure 1 shows a metal component produced by metal additive manufacturing.

Table 1. Nomenclature

AM	Additive Manufacturing
CAD	Computer Aided Design
DMLS	Direct Metal Laser Sintering
EOS	Electro-Optical Systems, Germany
STL file	Standard Triangulation Language file

Fig. 1: Metal component produced by Additive Manufacturing.

2. **DIRECT METAL LASER SINTERING**

Direct Metal Laser Sintering process was invented and patented by Pierre Ciraud in the 1970s and the first test system for DMLS was installed in 1994 after which the first commercial EOSINT M250 systems were installed in 1995. EOS is now the main manufacturer of DMLS technology. DMLS process creates three dimensional objects, layer by layer from CAD data using metal powders with heat generated by a CO_2 laser. Figure 2 shows a schematic diagram of DMLS. Once a CAD model is prepared and checked for any errors in the design, the file in converted to STL file format or Stereolithography file format. STL stands for standard triangulation language and can be defined as a triangular representation of 3D object. The surface of an object is broken into a logical series of triangles, each triangle being uniquely defined by a normal and three points representing its vertices. STL files are an unordered list of triangular facets representing the skin or outer surface of the 3D object. The tessellation size is user defined and depends on the fineness needed for the surface. Fine STL files are the ones where the surfaces are divided into a large number of triangles and are mainly used to achieve high accuracy and precision with good surface finish. Coarse STL files are the ones where the surface is divided into a smaller number of triangles and is mainly used where accuracy and precision are affordable because fine STL files tend to have many redundancies and are tedious to handle. STL files are generated through tessellation of accurate 3D models whose surfaces are approximated with triangular facets. The STL file generation follows the right hand rule and the vertex to vertex rule. To identify interior and exterior surfaces data about the triangle vertices must be stored in an ordered fashion, therefore a clockwise vertex ordering is used to define an interior surface and an anticlockwise vertex ordering is used to define an exterior surface. The vertex to vertex rule states that a triangle must share exactly two common vertices with each adjacent triangle so as to avoid redundancies [4,5,7,8].

The conversion of CAD data into STL file format causes some tessellation errors such as gaps which are missing facets, degenerate facets where edges of the facet are collinear and overlapping facets. Gaps usually occur during the tessellation at the intersection of curved surfaces, leaving gapes and holes along the edge of the part. A degenerate facet occurs when all of the facet’s edges are collinear in spite of all its vertices being distinct. This error usually occurs due to the stitching algorithm that attempts to avoid shell punctures. Overlapping facets may be generated due to numerical round off errors occurring during tessellation. Since the vertices are represented in floating point numbers instead of integers, numerical round off can cause facets to overlap if the tolerances provided are liberal [10]. Once the STL file is corrected of its errors, the file is transferred to the DMLS system where, depending on the orientation to minimize build time, costs and accuracy, it is mathematically sliced into a series of horizontal cross sections.

A thin layer of the atomized, heat fusible metal powder is deposited onto the part building cylinder within the temperature controlled build chamber with nitrogen atmosphere. An initial cross section of the object under fabrication is scanned on the layer of powder by heat generating CO_2 laser. The interaction of the laser beam with the powder elevates the temperature to a point of fusing the powder particles and forming a solid mass. This temperature obtained during fusing of powder particles is below the melting point of the major constituent metal in the metal alloy powder. The intensity of the laser beam is modulated to sinter the powder only in areas defined by the part’s geometry. The rest would remain in its powder form which eventually acts as support material for the product. When the cross section is completely drawn, an additional layer of powder is deposited via a roller mechanism or coater blade mechanism on the top of the previously scanned layer. In order to produce accurate parts, it is necessary to control the amount of energy transferred as the laser scans the powder. If the powder grains soften too much and begin to flow like liquid, shrinkage may become unpredictable. If the powder is not heated enough, coherent layers won’t form. The building chamber is heated to just below the melting temperature of the powdered materials so that only a slight amount of extra energy from the laser will sinter the powder grains. Heating the chamber also reduces the thermal shrinkage of the layers during fabrication. The chamber is filled with nitrogen to reduce the hazard of explosion. Powder spreading and scanning are repeated with each layer fusing to the layer below it. Successive layers of the powder are deposited and the process is repeated until the part is complete. As DMLS material is in powder form, the powder not sintered or fused during the process serves as a customized, built in support structure and there is no need to create support structures within the CAD design. After DMLS process the part is removed from the build chamber and loose powder simply falls off. Some DMLS prototypes require post processing such as sanding depending upon the application of the prototype built [9,11,12]. Figure 3 shows the working of Direct Metal Laser Sintering.

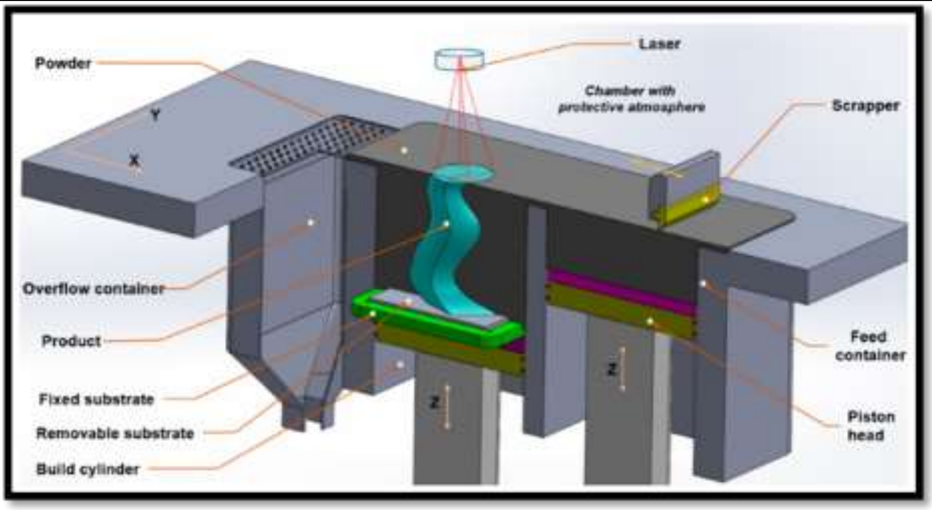

Fig. 2: Direct Metal Laser Sintering

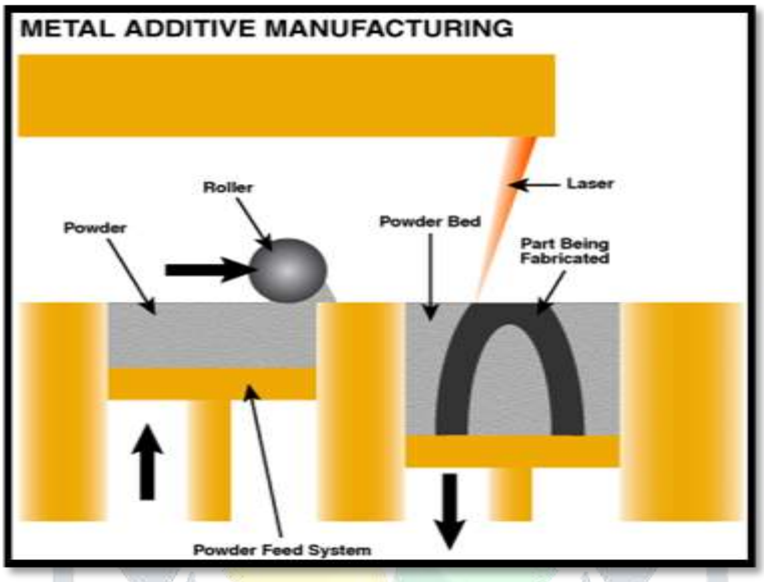

Fig. 3: Working of Direct Metal Laser Sintering

The time needed to build a particular part is dependent on the height of the part which is the number of layers, the complexity of the part which is basically the time required to scan each layer and the scanning speed of the laser which is determined by the material's melting temperature. Laser Sintering is bested suited to applications requiring parts with superior material properties. Although laser sintering materials are more expensive, sintered parts exhibit higher strength and resistance to weather, chemicals and heat. It is possible to create complex parts with inaccessible internal features because sintered parts don't require supports that must be removed after the build. Sintered parts because they are made of powders, tend to have a grainy surface finish and need some extra finishing operations as required by their application.

3. **ADVANTAGES AND DISADVANTAGES OF DIRECT METAL LASER SINTERING**

3.1 ADVANTAGES OF DIRECT METAL LASER SINTERING

- Good Part Stability: Parts are produced within a precise controlled environment, and the process and materials allow for the direct production of functional parts.
- No part supports required: The system does not require CAD developed support structures which saves time and effort.
- Little Post Processing required: The finishing achieved by DMLS is reasonably fine and requires minimal post processing such as sanding or particle blasting.
- No Post Curing required: The completed laser sintered part is solid enough and doesn't require further curing.
- The use of Advanced Software which reduce errors along the production.
- Life of the product produced is longer when compared to other Additive manufacturing processes.
- Virtually no Material Wastage: The excess metal powder can be reused.
- Human intervention is kept to a minimum.
- Whole Assemblies can be produced together rather than manufacturing each minute component independently.
- There is a drastic reduction in production time when compared to conventional methods.

3.2 DISADVANTAGES OF DIRECT METAL LASER SINTERING

- Large Physical Size of the Unit: The system requires a relatively large space to house it and additional space is required to house the storage tanks of the inert gases used for each build.
- High Power Consumption: The system consumes a lot of power due to the high wattage of the laser which is an essential part of the DMLS process.

- Poor Surface Finish: The parts produced have quite poor surface finish due to the relatively large size of the powder particles, which can be solved by post processing taking up more time and effort.
- Expensive Process: The production of parts using DMLS is quite expensive when compared to the costs of a few other Additive Manufacturing processes.
- Cracks and Internal Defects: These may be caused due to uneven distribution of the atomized metal powder layer or small fluctuations in the laser intensity.

4. **RESULTS & DISCUSSIONS:**

Additive Manufacturing is experiencing massive growth in recent years and is said to be the next step in the evolution of Manufacturing and is a vital part of the concept of Industry 4.0 or the next industrial revolution [1,2,3]. Additive Manufacturing gives a sense of flexibility never seen in design and manufacturing especially in the case of metallic components. Additive Manufacturing and DMLS still have many drawbacks like shorter life of products when compared to conventionally manufactured products and being expensive, but the advantages such reduction in material wastage, creating custom properties in products for suitable applications, freedom of designing and fabricating complex and intricate features with relative ease and the most important factor being reduction in production time [4,8].

According to the Wohler's Report 2021, there was a decline in growth of the Additive Manufacturing Industry in the previous year of 2020 from an average growth of 27.4% over to the past 10 years to only 7.5% growth in 2020. Figure 4 shows a chart from the Wohler's Report 2021 showing the growth in the production of additive manufactured parts by independent service providers.

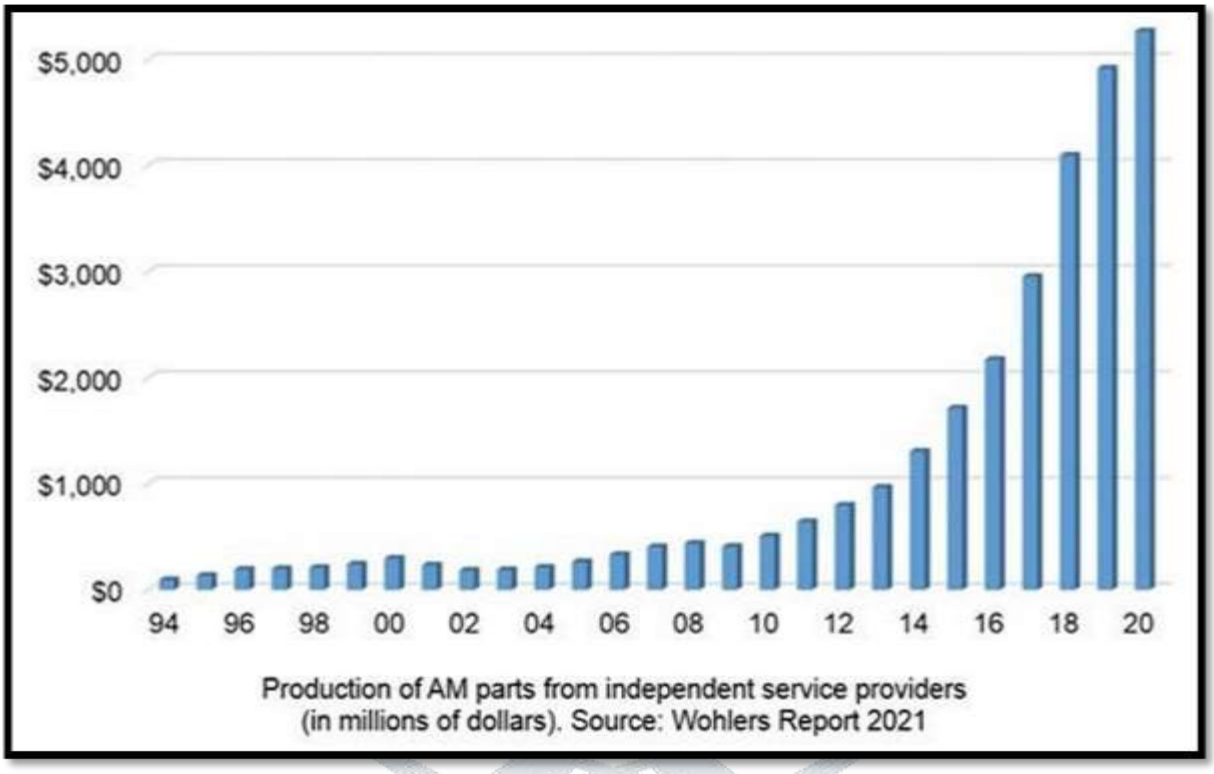

Fig. 4: A chart showing the growth in production of AM parts from independent service providers from the Wohler's Report 2021

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