Additive Manufacturing Processes: Selective Laser Melting and Electron Beam Melting – A Review

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Abstract- *According to ASTM F2792 "Additive Manufacturing is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer as opposed to subtractive manufacturing methodologies". Additive Manufacturing technologies has been widely used to produce components which should be at a quality least equivalent or way better than the conventionally produced components. While various materials are used in rapid prototyping, metal AM produces a high quality high strength structural components. Of all the metal rapid prototyping processes Selective Laser Melting (SLM) and Electron Beam Melting (EBM) are some of the important processes. Understanding the mechanisms, properties, quality, defects and their impact on the performance of these techniques is important in order to produce products of optimum quality. This paper gives a detailed analysis comparison of the basic principle, their mechanism, parameters and various types of factors affecting the SLM and EBM processes of Stainless steel-316 L.*

Keywords- Additive manufacturing, Electron Beam Melting, parameters, Selective Laser Melting,

I. INTRODUCTION

AM methods are rapidly replacing the conventional manufacturing techniques across all the industries due to its cost effectiveness and complex modelling capability. Though these techniques are adopted across all manufacturing sectors a lack of standardization still prevails in the field. The National Institute of standards and technologies (NIST) have identified the significant need for the proper standardization and certification of the AM technologies. NIST mainly focuses on the AM techniques used for metals such as Titanium, Stainless steel, and Nickel alloys due to their excellent applications in the various industries.

II. CLASSIFICATION OF METAL ADDITIVE MANUFACTURING

Several techniques have been used for metal rapid prototyping processes. The exact classification of the AM technologies has been a controversial thing still now. Different researchers classify AM based on different parameters. J.P.Truth classify AM methodologies based on the kind of raw materials used **[1]**.The classification by Williamson and his team were mostly sided towards academic where the practical point of view is not applicable **[2]**. American Society for Testing and Materials(ASTM) and International Standard Organization (ISO) have also classified additive manufacturing techniques based on various factors applicable but still there are many loopholes and drawbacks in the classification. The techniques used for additive manufacturing are classified based on four major factors namely material, energy, machine and tool and technology. The material may be in the form of wire, powder or in rod. The energy used may be laser beam energy, electron beam energy, ultrasonic wave or chemical energy. The classification of additive manufacturing technologies based on all the possible factors considered are mentioned as given in the below Figure no 1**[3]**.

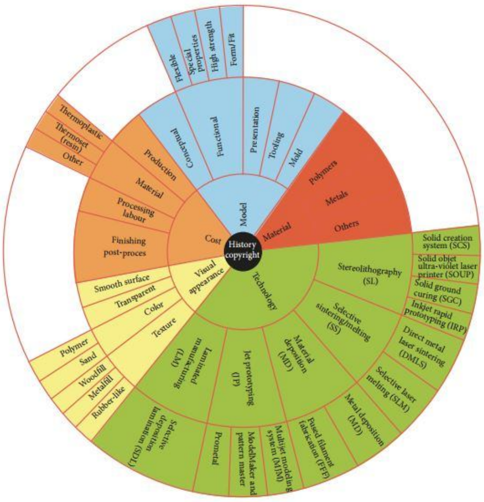

Fig .1 Classification of Additive manufacturing methodologies [3]

Powder based Additive manufacturing processes

Powder bed fusion and Powder injection are the two metallic powder based techniques. Of these powder bed fusion is one of the most commonly used process which can be classified into three categories based on the melting mechanism of the powder. They are fully melted, partially melted and polymer/resin assisted binding. The processes are again classified into various categories as mentioned in figure no.2 **[4]**.

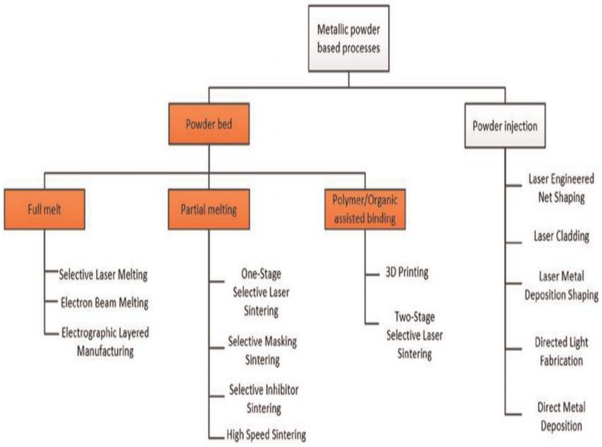

Fig.2. Type of metal based additive manufacturing processes [4]

Of all the processes given above selective laser melting and electron beam melting are two sparsely used processes. Both the processes are similar in their principle and mechanisms except the fact that SLM uses cold powder bed whereas the EBM uses a hot bed for the fusion mechanism.

III. SELECTIVE LASER MELTING

The Selective Laser Melting is one of the additive manufacturing technology started in 1995 at the Fraunhofer Institute ILT in Aachen, Germany. Later it was developed by MTT technologies located in Luebeck in northern Germany which makes the SLM a commercial technology available to all the manufacturing industries. SLM is one of the powder bed fusion process where the powder metal is selectively deposited over the substrate or previously deposited material as dictated by the CAD data **[5]**. It is more powerful than the Selective Laser Sintering (SLS) and Direct Metal Laser Sintering (DMLS) since the energy of the laser beam is high enough to melt the entire metal powder. The entire process is done under the inert gas atmosphere like N_2 or Ar depending upon the reactivity of the metal used. In addition, the entire setup is maintained under high pressure conditions. The substrate is heated up to a temperature of about 250 to 300^{o}C in order to minimize the cooling rate. The metal parts manufactured have very less or no porosity. The experimental setup of Selective Laser Melting process is given in the Figure no

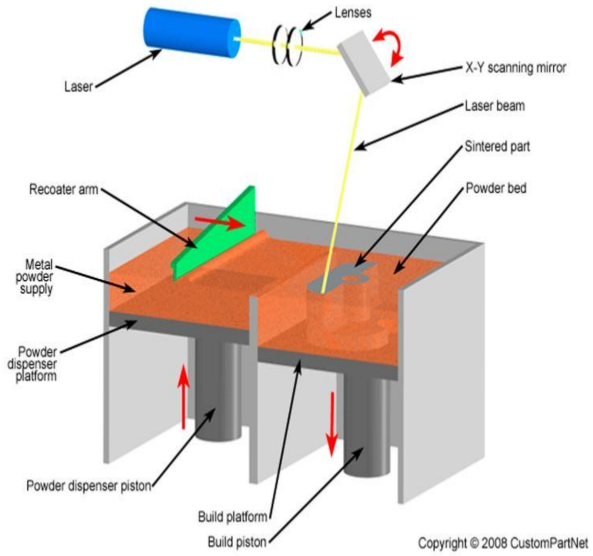

Fig 3. Selective Laser Melting [Courtesy to CustompartNet]

Process parameters

The selection of optimal parameters for the process is very crucial since it decides the final quality of the products **[6,7]**. The process parameters of the Selective Laser Melting are given in the below figure no.3 **[8].**

Materials Used

SLM is one of the most versatile process which can process a variety of materials such as 316L and 17-4PH stainless steels, H13 tool steel, Al-Si-12Mg and Al-Si-10Mg aluminum alloys, CP-Titanium, Ti-6Al-4V, Ti-6Al-7Nb, CoCr, and nickel-based alloys 625 and 718 **[9]**.

IV. ELECTRON BEAM MELTING

The Electron Beam Meting is a powder bed fusion process which is similar to that of the Selective Laser Melting(SLM) except the fact that an electron beam is used to fully melt the powder metal particles whereas in SLM a laser beam source is used. Electron Beam Melting has a bed temperature of about 850K and do not produce a fine microstructure as that of SLM **[10,11]**. EBM has a faster build rate than the SLM which makes it more powerful **[12,13]**. The EBM experimental setup is given in the Figure No as below.

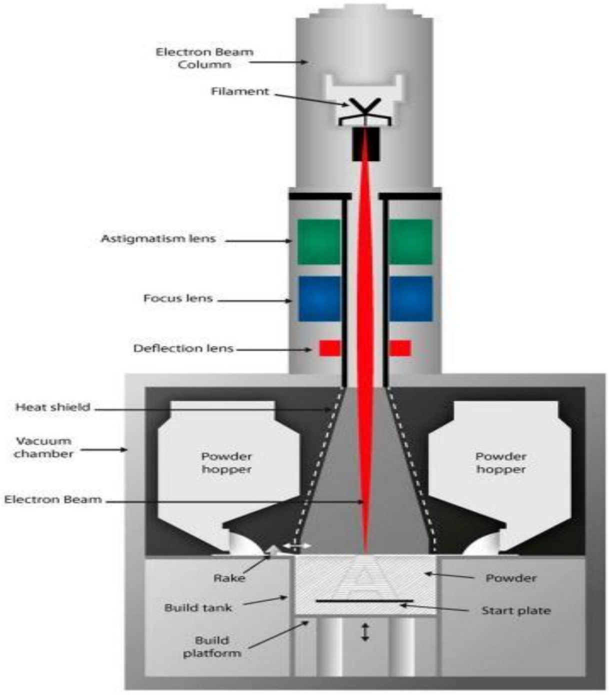

Fig 4. Electron Beam Melting [Courtesy to CustompartNet]

Process parameters

The EBM process involves more number of process parameters than the SLM process. The important process parameters of EBM include beam power, beam focus beam scanning velocity, beam diameter, beam line spacing, plate temperature, speed, and power of the beam, contour strategies, pre-heat temperature and scan strategy.

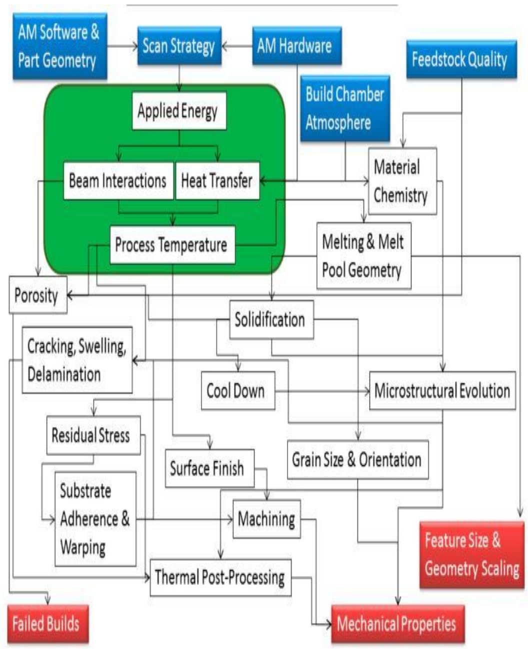

Fig 5. Process parameters of EBM and SLM [14]

Materials Used

The number of materials that can be processed using Electron Beam Melting is far less than the SLM. The materials that can be processed using electron beam melting are Ti grade 2, Ti6Al4V, Inconel 718, CoCrMo **[15]**.

Properties of SLM and EBM

Since the number of process parameters is more in the electron beam melting, the process parameters significantly affects the quality of the final component. The process is more expensive than that of the SLM. Additionally, the size of the parts that can be produced using EBM is limited which makes it worse. The EBM process takes place in vacuum atmosphere while the SLM process takes place in inert gas atmosphere. This is to prevent the collision of fast moving electrons with the gas molecules. However, electron beam melting can be used to process brittle materials that cannot be processed under SLM. The electron beam used is focused multiple times in the layers to melt the metal powder fully. This makes the electron beam melting more time consuming process than that of the SLM **[5]**. The comparison of properties of EBM and SLM are given in the table

Table no 1. Comparison of properties of materials produced by EBM and SLM [16]

Characteristic	EBM	SLM
Thermal source	Electron beam	Laser
Atmosphere	Vacuum	Inert gas
Scanning	Deflection coils	Galvanometers
Energy absorption	Conductivity limited	Absorptivity limited
Powder pre-heating	Use electron beam	Use infrared heaters
Scan speeds	Very fast, magnetically driven	Limited by galvanometer inertia
Energy costs	Moderate	High
Surface finish	Moderate to poor	Excellent to moderate
Feature resolution	Moderate	Excellent
Materials	Metal (conductors)	Polymers, metals, ceramics

SLM and EBM for metals

Additive manufacturing techniques are used to produce various alloy components using stainless steel. Various researchers have been working in the improvement of efficiency of the components produced in the AM techniques. The major factors that has been changed includes the process parameters, working environment, scanning methodology, energy applied, pre-heating and the source of energy **[17,18,19]**.

Stainless steel 316L

Stainless steel 316L grade are the most commonly used steel after 304. The major constituents of stainless steel 316L are iron, chromium (16-18%), nickel (10-12%) and molybdenum (2-3%). It is commonly used in petrochemical industry, food processing, marine applications and architectural applications **[20]**. Qi et al modified the scanning method of the selective laser melting. They change the scanning method by combining the split and rotating mode of scanning along with the zig zag motion of scanning to produce components. By this type of scanning 316L stainless steel components are fabricated **[21]**.

Table no 2. Compositional percentage of metals (% in weight) in Stainless steel 316L [27]

	#1	#2	#3	#4	#5	#6	#7
B	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	3.9	3.6	4.1	4.0	5.6	14.0	10.4
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O	0.5	0.0	0.0	0.0	0.6	13.0	3.4
Si	0.5	0.4	0.4	0.3	0.4	0.4	0.5
P	0.0	0.0	0.0	0.0	0.1	0.1	0.1
S	0.1	0.0	0.2	0.2	0.0	0.0	0.0
Cr	19.4	19.5	19.8	19.8	19.1	14.7	18.0
Mn	1.6	1.4	1.1	1.3	2.4	1.3	1.4
Fe	61.2	60.8	61.7	61.6	58.5	45.7	54.2
Ni	11.7	12.2	11.5	11.8	11.7	8.7	9.5
Mo	1.2	2.0	1.3	1.0	1.6	2.1	2.6

Deng et al produced stainless steel 316L parts by using SLM and the microstructure and tensile test of the produced components are examined **[22]**. They observed that the SLM produced stainless steel parts have higher tensile strength than the conventionally casted parts. Casavola et al used SLM to produce stainless steel components to study the residual stresses that develop during the process. It is found that the residual stresses are developed more during the solidification stage of the process **[23]**. Tucho et al studied the porosity levels in the stainless steel 316L that are fabricated using SLM **[24]**. Barto lo meu concluded that wear resistance, hardness and tensile strength of stainless steel 316L were highest produced by SLM among all the casting and hot pressuring processes **[25]**. On the other hand, Silvia Vock et al described that EBM requires pre heating of the material up to a temperature of about 600^{o} C **[26]**. The composition of weight percentage of various metals in stainless steel 316L produced by EBM process conducted by Mihaela Nastac as given in the table 2 **[27]**. Yi Zhang et al concluded that the yield strength and the ultimate strength of the stainless steel 316L produced are higher than that of the parts produced by SLM. The high cooling rate produced in SLM increases the strength of the Stainless steel 316L **[28]**.

V. CONCLUSION

According the focus of the manuscript, we have studied the processes of Selective laser melting and electron beam melting. The summary of the paper is listed as below

1. The various process parameters of the processes such as beam power, beam focus beam scanning velocity, beam diameter, beam line spacing, plate temperature, speed, and power of the beam, contour strategies, pre-heat temperature and scan strategy are studied.
2. EBM produced stainless steel parts have higher strength, ductility and toughness than that of the SLM produced parts.

3. The strength and ductility of the SLM produced 316L stainless steel parts decreases with the higher temperature but the ductility of the parts increases at a temperature of 250^{o}C.
4. The parameters of the stainless steel parts produced by EBM process are still an unexplored area to be studied.
5. Further experiments can be focused on changing the scanning method, building time, thickness of the layers produced by EBM process to improve the strength of the stainless steel 316L.

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