# Additive Manufacturing: A Brief Study on Selecting Laser Melting Technolgy

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***Abstract*— In today's day and age of technological advancement, manufacturing plays a vital role in safeguarding our present and building our future. The different ways of machining materials has evolved gradually from the Stone Age to the Iron Age and so on and has reached a point where human civilization has achieved creation of unimaginable technologies to build this world in a better and more efficient way. Additive manufacturing is such an aspect of this technological milestone which is developing vastly. This is a work on additive manufacturing technologies, specifically the use of Selective Laser Melting methods and a discussion of different aspects related to it, such as the processing parameters and the material properties and characteristics of the fabricated part. In simple words, Selective Laser Melting is an Additive Manufacturing method where a high power laser beam is used to melt powdered form of material and put this molten material layer by layer to fabricate the desired part. This review work enlightens the use of Selective Laser Melting in today's world. This review work provides vital information with regards to the parameters, material properties, material selection and an overview of additive manufacturing specifically the selective laser melting method.**

***Keywords*— Additive Manufacturing, Selective Laser Melting, Rapid Prototyping, 3D Printing, Processing Parameters**

## I. Introduction

Additive manufacturing is a prevailing technological advancement in the field of manufacturing which is opposite to the subtractive manufacturing in nature, however the fundamental motive is similar to that of conventional ways i.e., to build parts affordably, efficiently and logically without wastage of resources. These fundamental motives are almost quite impressively fulfilled by this technology. It is the type of manufacturing where parts are made by adding materials layer by layer rather than subtracting them like in the case of the conventional ways. Within a span of time this technology has evolved in many ways such as in terms of productivity, efficiency, development of new techniques through continuous research and analyses of the subject. Some of the most popular and promising methods of AM are Selective Laser Sintering, Selective Laser meting and Electron beam melting. The advantage of using this technique is its ability to built very complex structures of almost all sizes efficiently with regards to time and capital.

Selective laser melting or shortly SLM is a very prominent method of AM where a high power laser beam is used on the powder bed of the material to melt it and form layers after rapid solidification. This layer by layer deposition of materials continues till the desired structure is achieved. This method allows producing some of the most complex designs such as implants used in medical and dental industry. However, there are various factors which affect or influence the machining process which are discussed in this report. Few of this parameters are the laser power, scanning speed, powder grain size, build direction etc. the SLM finds its use in various prominent industries such as aerospace, medical and automotive industries.

This is a review work or study of AM into details, precisely the SLM method of it. It reviews the technology and the influencing parameters involved with it. The second chapter showcases a description of the AM in general depicting the advantages, methods, present and future aspect of the technology. The third chapter's motive is to provide an introduction to the SLM method of AM and the factors which influence the machining of parts using SLM. A literature review is presented in the fourth chapter depicting the works and findings of different researchers related to the subject area. Finally, the fifth chapter discusses the conclusion or the findings from this study.

TABLE I. LIST OF SYMBOLS AND ABBREVIATIONS

| Symbols/ Abbreviations | Meaning |
|---|---|
| AM | Additive manufacturing |
| 3D | 3- dimensional |
| RP | Rapid Prototyping |
| CAD | Computer Aided Designing |
| STL | Steriolithographic |
| FDM | Fused deposition modelling |
| EBM | Electron beam melting |
| kW | Kilo Watt |
| SLS | Selective laser sintering |
| CO2 | Carbon dioxide |
| LOM | Laminated object manufacturing |
| CAD | Computer aided manufacturing |
| SLM | Selective laser melting |
| LPBF | Laser powder bed fusion |
| DMLM | Direct metal laser melting |
| MPa | Mega Pascal |
| O2 | Oxygen |
| mm3/s | Cubic millimeter per second |

## II. ADDITIVE MANUFACTURING

The term manufacturing is defined as machining a solid block of material to the required shape using a machine, where the chips are removed and considered as scrap [1]. The American Society for Testing and Materials (ASTM) has defined additive manufacturing as ''the process of joining materials to make objects from 3-dimensional model data, usually one layer upon another, which is quite opposite to subtractive manufacturing technologies [2]. In contrast to the conventional manufacturing which is material subtractive in nature, AM is material incremental in nature, where material is added in layers and all the layers of material are bonded to make the 3-dimensional-shape. Other names used for AM are additive processes, additive fabrication, additive layer manufacturing, freeform fabrication, layer manufacturing, and additive techniques [2]. The AM process takes the input information from a computer-aided design file which is later converted to a stereo lithography file. In the process of AM, the drawing is made in the CAD software where it is approximated by triangles and sliced containing the information of each layer that is going to be printed. There are various names by which the term AM is addressed and some of these names are tabled in table 1.

TABLE II. NAMES USED FOR ADDITIVE MANUFACTURING

| Initials | Other Names |
|---|---|
| Additive | Additive manufacturing (AM) |
| | Additive layer manufacturing (ALM) |
| | Additive digital manufacturing (DM) |
| Layer | Layer based manufacturing |
| | Layer oriented manufacturing |
| | Layer manufacturing |
| Rapid | Rapid technology |
| | Rapid prototyping |
| | Rapid tooling |
| | Rapid manufacturing |
| Digital | Digital fabrication |
| | Digital mock- up |
| Direct | Direct manufacturing |
| | Direct tooling |
| 3D | 3D prnting/ modeling |

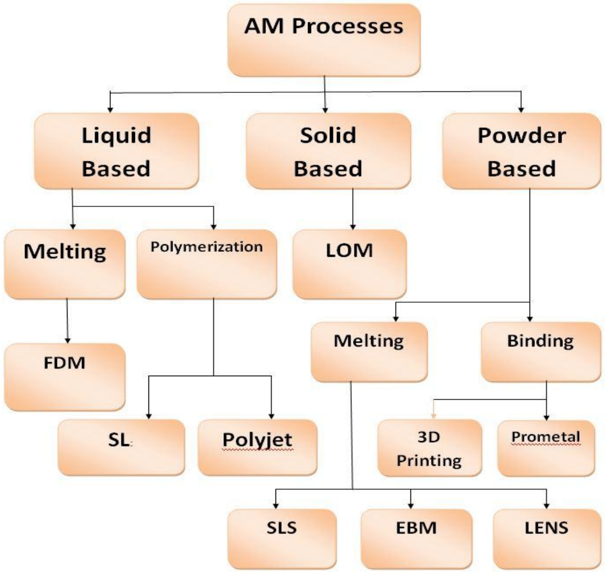


Fig. 1. Flow chart of AM methods

AM is a new comparatively new technology and no standardization work had been done until 1990 in Germany [4]. In 2007, a special recommendation dedicated to Rapid Prototyping was created under the supervision of the German Society of Mechanical Engineers, VDI. It was published in autumn of 2008. As of 2009, the American Society of Mechanical Engineers (ASME) in cooperation with the American Society for Testing and Materials (ASTM) initiated the development of their own standardization procedures [4].

*A. Methods of Additive Manufacturing*

Rapid Prototyping- RP is the 1st known form of AM used to manufacture items using CAD softwares and it was developed in the 1980s. This technology was created to help the realization of what engineers have in mind and it allows for the creation of printed parts, not just models. RP greatly reduced the cost and time of the product development and also could manufacture any complicated design which was difficult to machine by the conventional ways. In the present day, it is not quite widespread, however used by the students, professors, scientists and the engineers related to the research field for rapidly creating prototypes of the models they are working on.

Steriolithography- It was evolved by the 3D systems Inc. and one of the first rapid prototyping methods used. a liquid-based process that consists in the curing or solidification of a photosensitive polymer when an ultraviolet laser beam makes contact with the resin. This process starts with creating a model in CAD software which is then translated into a STL file, where the model is differentiated into parts containing the information of each layer. The resolution and thickness of each layer depends upon the equipment used. Here, a platform is used to support the pieces and the overhanging structure. The Ultraviolet laser beam is applied to the resin solidifying specific locations of each layer. When the layer is finished the platform is lowered and finally when the process is done the excess is drained and can be reused. The fundamental principle of this process is the photopolymerization, which is the process where a liquid monomer or a polymer converts into a solidified polymer by applying ultraviolet light which acts as a catalyst for the reactions; this process is also called ultraviolet curing. With a higher resolution an advanced version of this method has been developed and is called microsteriolithography [3].

Prometal- Prometal is an AM process to build injection tools and dies. It is a powder-based process where stainless steel is used. In this process, a liquid binder is spurt out in jets to steel powder. The steel powder is stored in a powder bed which is controlled by build pistons that lowers the bed when each and every layer is finished and a feed piston which supplies the material for each layer. After finishing, the residual powder is always removed.

Fused deposition modeling (FDM)- FDM is an AD process in where a thin filament of plastic is fed to a machine in which a print head melts it and extrude it in a thickness nearing 0.25 mm. Most common materials used in this process are acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyphenylsulfone (PPSF), PC-ABS blends, and PC-ISO. The main desirability of this process are that no chemical post-processing is required, no resins to cure, it is less expensive machining and materials result in a more cost effective process. Figure 3 shows the basic process of FDM.

Electron beam melting (EBM)- EBM is a type of AM where the material used as feed is in the form of powder. Here, the powder of the material is melted by a high voltage electron beam typically in the range of 30kW to 60kW. Unlike the FDM, this process is used to build metal parts and therefore, it is carried out in a vacuum chamber to avoid oxidation of the material. EBM can also be used to build a high variety of pre alloyed metals and also be used in outer space manufacturing technologies as the process is carried out in the vacuum [13].

Selective laser sintering (SLS)- SLS is an AM process where a powdered material is sintered or fused by the application of a CO2 laser beam. The chamber in which the process is carried out is heated to near about the melting point of the material and then the CO2 laser fuses the powder at a particular location for each layer specified by the design of the prototype. The particles are loosely packed in a bed, which is controlled by a piston that is lowered to push out the same amount of the layer thickness each time a layer is completed. One of the most important advantages of this process is that it can be used to machine a lot of various materials like plastics, metals; ceramics; composites etc. acrylic styrene and polyamide are some polymers which can be machined by SLS. Moreover metals like copper and composites such as fiber glass are also machined by SLS.

Laminated object manufacturing (LOM)- LOM is a combination of the additive and subtractive manufacturing techniques which is used to create models layer by layer and part by part. Unlike previously discussed techniques, this process uses feed materials in sheet form. The layers created by using both additive and subtractive processes are bonded together by application of pressure, heat and adhesive coating. Similar to the SLS process, a CO2 laser cuts off the material sheet to shape the model as per the CAD design information. Low manufacturing cost and no requirement of post processing are some of the advantages of this process. Also it can be used to build large parts.

Polyjet - Polyjet is an am process which is used to build models by using inkjet technologies. Here the inkjet moves in x and y direction or axes which deposits a photopolymer which is cured by ultraviolet lamps after each layer is finished. The layer thickness achieved in this process is 16 μm, so the produced parts have a high resolution. However, the segments generated by this process are frailer than others like stereolithography and selective laser sintering. A gel-type polymer is wield for assisting the overhang attributes and after the process is completed this material is water jetted. With this operation, segments or parts of multiple colours can be built.

### *B. Advantages of Additive Manufacturing*

- The costs involved with the production of a model by AM is cheaper in comparison to the conventional subtractive manufacturing [1][2][3][5][9][10].
- Very complex parts can be manufactured with ease by the use of AM technologies unlike in the case of conventional machining process [3][4][7].
- Alteration of original design can be done with ease [7].
- Moving parts such as hinges and bicycle chains can be printed in metal directly into the product, which can significantly reduce the part numbers [1].
- It is less time consuming as it can create a prototype with a 3-D printer immediately after finishing the part's STL file [1][2][7].
- No highly skilled professional is required to print a part using 3D printing unlike in the case of subtractive machining which requires knowledge of CAM [3][5][7].
- The wastages of materials are quite reduced by AM [3].

## III. SELECTIVE LASER MELTING

SLM is an AM process in which a material in the powdered form is melted with the help of a high-power laser and then solidified in successive layers to produce a simple or complex 3D physical model [11][13]. It is developed by Dr. M. Fockele and r. D. Schwarze of F & S Steriolithographietechnik GmbH, with Dr. W. Meiners, Dr. K. Wissenbach and Dr. G. Andres of Fraunhofer ILT to fabricate metallic components from powders [5]. This process uses powders, predominantly of metals as raw materials. A layer of the material powder is deposited on the substrate plate, where the laser heats and melts the powder particles following the CAD design. The other known terms used for SLM are laser powder bed fusion (LPBF) or direct metal laser melting (DMLM). The SLM technology generally uses particles in powdered form where the particle sizes range between 20 to 50 mm and layer thicknesses range between 20 to 100 mm [19]. Figure 4 shows the schematic diagram of SLM process. The machine performing SLM has a powder handling platform whose role is to collect, deliver powder and build parts from it. The machine is also equipped with a blade known as the re-coater which is used to spread the powder, a laser unit and a scanning unit. Here, the 3D model is prepared using CAD software and then converted into a STL file suitable for industrial use, which is then imported by the SLM machine to determine the printing path by the scanner and finally printed by use of the laser unit. The powder-delivery platform is lifted up to a certain height according to the powder height of the preset layer thickness from the building platform. The blade or re- coater is used to spread the metal powder on the substrate plate which is attached to the building platform and as a result forms the first layer before being melted by the laser. After the first layer is completed, the building and collector platforms are moved down, while the powder-delivery platform is raised. The building chamber is airtight and kept in vacuum condition or inserted with inert gas to prevent oxidation as the building materials are mostly metals. There have been recent efforts to scale down the technology to work with particles sizes of less than 10 mm and layer thickness of less than 10 mm. This new approach of SLM is known as micro SLM, and it is expected to evolve continuously and find applications in cell biology, biomedical science, and clinical diagnostics [13].

There are many priviledges of SLM, however the most remarkable of them is that parts fabricated by SLM are free from internal stresses and defects which are prone to parts fabricated by conventional procedures [15]. The summary of pros and cons of SLM can be understood from the table 2, where it has been discussed briefly.

TABLE III. ADVANTAGES AND DISADVANTAGES OF SELECTIVE LASER MELTING

| Advantages | Disadvantages |
|---|---|
| High accuracy | Accuracy requires longer durations in the process |
| Functionality | High surface roughness and high residual stress |
| Minimal post-processing | Anisotropic properties |
| Wide variety of materials (some under development) | Deficiency of quality on-line control |
| Allows the creation of complex and unique shapes from metal powders | High cost of equipment and materials |
| Surface structuring (including micro- and nano-structuring) | Requires an inert gas supply |
| High recyclability of the raw material | Difficulty in removing powder from small channels |

### A. *Principle of Selective Laser Melting*

The SLM fabrication technique involves heating and then melting of powder materials with laser beam and rapid solidification of the melted material to form the desire part. There are some phenomena which are salient in order to understand this process, they are as follows- (a) absorptivity of the powder material to laser irradiation, balling phenomenon and the thermal fluctuation experienced by the material during the process [6]. These phenomena are discussed in details in the next section.

Laser and material interaction- As discussed earlier that the SLM process was developed to build components by heating and melting materials using a high power laser beam. Alike SLS, the SLM process utilizes a high power CO2n laser beam of wavelength around 10.6 µm that is incident on to the material powder.[5]. From past studies, it can be observed that the energy absorption by the powder material can be drastically different from that of the bulk material. For instance, the titanium powder has absorption of 77% whereas the bulk titanium absorbs only 30% of the total radiation. There is a high rate of absorption of radiations in powder materials because of multiple reflections of laser beam in the powder bed and this result in higher optical penetration depth. Apart from laser parameters, the powder size and powder distribution also have significant effect on the process [9].

Balling phenomenon- In SLM process, the molten metal forms spheroidal beads because of insufficient wetting of the proceeding layer and the surface tension; this is called the balling phenomenon. It has a negative impact of the fabrication process as it hinders the formation of continuous melt lines which results in rough and bead shaped surfaces. In severe cases, balling may aggravate the process and obstruct the powder coating mechanism with large metallic beads that extends above the powder bed [16]. Li et al. has observed that the balling effect can be significantly reduced by keeping the O2 level to 0.1%, applying a combination high laser power and low scanning speed or applying re-scanning of laser

Thermal fluctuations- The materials experience a lot of thermal fluctuations during the SLM process and thermal fluctuations result in the residual stresses in the material. It also leads to crack formation and delamination of the parts [5]. Shiomi et al. studied the residual stresses involved in fabricating parts made of chrome molybdenum steel mixed with nickel and copper phosphate powders. It was observed that heat treatment of these parts at 600- 7000C for 1 hour can significantly reduce the residual stresses by 70%. Moreover, re- scanning of laser reduces residual stresses by 55% and preheating the powder bed to 1600C can reduce the residual stresses upto 40 %. The issue of crack formation and delamination mostly occurs in the ceramic materials. These problems can be mitigated by implementing preheating, right scanning strategies and post process heat treatments.

### B. *Processing Parameters*

The SLM technology involves a sum of few processing parameters which mainly affects the mechanical properties of the fabricated parts. Moreover, the thermal cycle experienced by the powder metal is directly affected by these parameters and also consequently influence the mechanical properties and microstructure of both the static and cyclic loadings [15]. Different combination of these parameters results in a set of different effects on the fabricated parts. Hence, efforts have been made to understand the correlation between these parameters for how they affect the properties of the fabricated parts. The processing parameters are mainly classified into laser-dependent and build- dependent parameters.

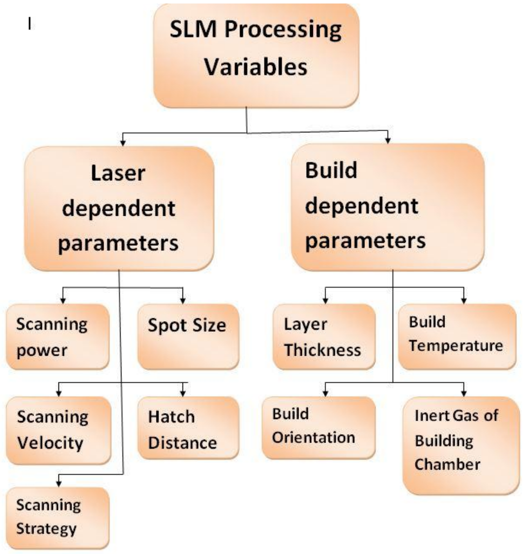


Fig. 2. Processing parameters of Selective Laser Melting

The laser power and the scanning speed have significant influence on the finished product. These processing parameters govern the energy transferred to the metal powders, which directly impacts the dependent melting temperature for the liquid phase in the melted parts [14]. The conditions of melting depending on the processing parameters are shown in table 3.

TABLE IV. CONDITION OF MELTING OF FEED MATERIALS COMBINED WITH PROCESSING PARAMETERS [14]

| Conditions | Descriptions |
|---|---|
| No melting | Delivered laser energy is inadequate to affect the powder and left a lot of unfused powder particles. |
| Partial melting | Combination of low scan speed (<0.06 m/s) and medium laser power formed a liquid phase on the surface of particles. After crystallization, unmelt cores of particles joined into the coarsened balls. The surface illustrated the first type of balling |

| | |
|---|---|
| | phenomena |
| Melting with balling | Combination of high scan speed (≥0.06 m/s) and high laser power generated thin, long, and cylindrical lines of liquid scan track shapes, which later broke up into rows of coarsened beads. This shows the results of surface tension reduction. |
| Complete melting | Enough laser energy formed permanent tracks of molten metal material. A fully melted compact solid surface formed continuous lines by the tracks formation. |

Layer thickness is another build- dependent parameter which influences the porosity of the fabricated parts. The porosity subsequently determines the mechanical properties of the parts such as tensile strength and hardness [13][14][16]. It is seen that when the layer thickness decreases the porosity of the parts also decreases when the other parameters are controlled. The reason behind this phenomenon is that loose powder has a considerable amount of air in between the particles and when the powder gets melted, air is trapped in between the spaces and as a result air bubbles come into existence [14]. High porous parts are obviously not preferred in most of the applications as it weakens the material strength and surface finish.

Another vital build- dependent parameter is the build orientation, i.e., the Z, and it is defined as the acute angle between the vertical axis of the build platform and the longitudinal axis of the given product [14]. Shifeng et al. observed through his experiment that the tensile property of fabricated 316L stainless steel showed better ductility when horizontally built where as the vertically built product showed an optimal combination of strength and ductility [14].

### *C. Mechanical Properties of Fabricated Parts*

It is quite obvious to discuss about the mechanical characterization of the fabricated parts by SLM. Physical properties such as tensile strength, hardness, fatigue.

Tensile and elongation- the static tensile strength of the fabricated parts depends on the density of the components, also the microstructures formed during the process [11][17]. The increase in both the yield and ultimate tensile strength is because of the grain refinement and it is described by the phenomenon called the Hall- Petch strengthening [21]. The tensile characteristics of the parts greatly depend upon their microstructures.

Hardness- The hardness of the fabricated parts are influenced by the density and the microstructures present. Generally, the parts produced by SLM method shows better hardness characteristics due to better density further due to minimum porosity.it is observed that the hardness of materials produced by SLM technique are generally higher than that of materials produced by wrought processes [14].another reason for the improved hardness of parts fabricated using SLM is the condition of microstructure phases present in the material. For instance SLM TI6AL4V part has higher hardness than that which is produced by wrought because of the presence of martensite phase regimes and higher grain refinement [14].

Fatigue- Harun et al. conclude that the fatigue life of a SLM fabricated material is quite moderate in comparison to that of parts fabricated by conventional ways. The factors influencing fatigue life of parts are microstructure, porosity, surface finish and residual stresses. The surface roughness and defects inherited by parts in SLM process deteriorates the fatigue life of the parts. As the parts fabricated by SLM have higher surface roughness, it gives rise to higher stress concentrations in them which finally results in lower fatigue life of the parts. The fatigue life of materials can be improved by the induction of post processing such as surface finishing methods or heat treatments [12]. Riemer et al. in his observations found that the fatigue life of 316L stainless steel has a fatigue life of 108 MPa which is quite less than that of the traditionally fabricated part with values ranging from 240- 381 MPa. He tried to fix this by adapting heat treatment to the material fabricated by SLM.

Microstructure- Microstructure is related to the grain size of the fabricated parts. The finer and smaller the grain size of a part is, the better the microstructure of that part. As discussed in the earlier sections, the microstructure has a significant influence on the other mechanical properties of any part such as tensile strength hardness. Better microstructure results in better hardness and tensile strength of the material. The SLM fabricated parts have better microstructure of finer grain sizes due to the rapid solidification of the laser heated materials [19].

Relative density- relative density is defined as the density of material attained by SLM to the theoretical density of the bulk material. it is better to have a higher relative density of material to have better mechanical properties. Most of the iron- based materials of SLM steels have a relative density higher than 90% [9].

## IV. LITERATURE REVIEW

Morrow et al. studied the environmental impact of laser based AM methods and observed that these methods can be greatly beneficial in reducing environmental waste and cost resulting in somewhat eco- friendly manufacturing [2].

Kellens et al. studied the energy efficiencies of SLM and SLS processes. He concluded that the environmental impact of these processes are very limited and evidences relating to energy efficiencies of these processes are lacking and work is needed to be done in this subject area. He defined the energy efficiency related top material fabrication is the ratio of output energy content of the product to the total energy used in the fabrication operation. For the above mention fabrication processes the energy efficiency is around 8.6% which is an excellent figure [2].

Herzog et al. in his study of AM found out that high temperature gradient involved in AM results in finer grain structure of a better microstructure added with excellent strength. It has also been observed that the complex thermal cycle in SLM involves a constant reheating of formerly solidified surfaces during the operation that results in in-situ heat treatment. This in- situ heat treatment results in some desired as well as undesired effects such as deposition of brittle phases into more ductile variants, separation of alloying elements and higher grain growth. The negative effects can be nullified by post processing heat treatment methods [3].

Furthermore, Herzog et al. states through his research that the mechanical properties of parts fabricated by implementing powder bedded, laser indulged fabrication methods are better than the wrought methods, of materials such as different steel grades, aluminum alloys and titanium alloys [3].

Gebhardt et al. stated through his studies on SLM that like any other manufacturing technology, the SLM method also needs proper selection of materials, controlled and task specified processing parameters, engineering design and management and technical skills [4].

Yap et al. made an extensive study on the aspects of SLM. Through his work he discussed about the processing parameters and materials used in the process. One such parameter is the absorptivity of irradiation of the materials. Lead (Pb) powder of has the highest absorption rate wrt. the dense substance. Due to toxic characteristics of Pb its application is quite limited but apart from it titanium powder shows the highest absorption [5].

Yap et al. has also made a detailed study on the SLM material properties. Table 4 showcases some of the highest relative densities obtained various SLM materials..It is quite evident that different grades of steel, alloys of titanium, ceramics like Al2O3-ZrO2 and composites like ZrO2/Waspaloy have the highest relative densities [5].

TABLE V. COMPARISON OF HIGHEST RELATIVE DENSITIES OF DIFFERENT MATERIALS [5]

| Materials | Relative density (%) |
|---|---|
| Fe-Ni-Cr | 99.50 |
| H20 steel | 99.50 |
| 316L steel | 99.90 |
| AISI Marage 300 steel | 99.99 |
| Ti-6Al-4V | 99.98 |
| TI-6Al-7Nb | 99.95 |
| Inconel 718 | 99.98 |
| Hastelloy | 99.75 |
| Nimonic 263 | 99.70 |
| CoCr | 99.94 |
| AlSi10Mg | 99.50 |
| K220 | 99.90 |
| 24 Carat gold | 89.60 |
| Cu based powder | 95 |
| Al2O3-ZrO2 (ceramic) | Close to 100 |
| Al2O3-SiO2 (ceramic) | 95 |
| ZrO2/Waspaloy (composite) | 99.66 |
| SiC/Fe (composite) | 99.30 |
| TiC/Ti (composite) | 98.30 |
| TiN/Ti5Si3 (composite) | 97.70 |

Meiners et al. presented the comparison of the rate of material building in different SLM methods. The material used in this literature was AlSi10Mg which was subjected to SLM with laser beam diameter of 200 µm. the buildup rate could be increased from 4 mm3/s to 21 mm3/s i.e. around 525% growth in the material buildup rate. Moreover the work also concludes that if post processing heat treatment is done at 250 0C, then this alloy can be prevented from cracks and other material distortions [6]. To perform this experiment a SLM machine was modified by using a 1 kW laser beams with multiple beam optical design.

Kruth et al. in his study has shown the mechanical properties of different metals used in the SLM process which can be seen in table 5. Here, the titanium based alloy has shown the better properties than its steel counterparts [7]. The study also states that rapid prototyping techniques such as SLS and SLM are vastly growing due to the better build rates, better properties possessed by the fabricated parts and cost effectiveness and minimal wastage of material [7].

Louvis et al. studied the selective laser melting of aluminum components. A study was done on the effect of hatch distance and scanning speed on the relative density of aluminum parts. Relative density rises with the rise in the laser power. At 50 W laser power the relative density of aluminum first increases with the increase in scanning speed and then decreases with further increase in it. Whereas, at 100 W of laser power the relative density somewhat decreases with the increase in scanning speed. Also, better results in the relative density can be found when the hatch distances of the particles are of 0.1 to 0.15 [9].

Also, there are few negative aspects which were pointed out in the studies made by louvis et al. the development of thin oxide film after every layer deposited is one of such deformities which needed to be addressed. This issue of development of oxide is similar to casting methods. If high density parts are to be build these oxide films are to be removed frequently after each layer has been deposited, which is quite impractical. Therefore another way to counter this problem is by stirring the melt pool of the material after every layer deposition, which gives a better result in the finished product [9].

Ngo et al. states that the AM methods such as SLS and SLM are superior as compared to other Am methods such as fused deposition modeling because of greater mechanical properties and qualities attained by the fabricated parts [11]. The SLM, SLS and DED methods are the most common methods implemented to fabricate metals [11].

Loeber et al. had a detailed study on the difference between SLM and EBM produced cylindrical specimen of Ti(46-48)Al-2Cr-2Nb. Both the methods are functionally similar but their results vary. Parts produced by the EBM have higher relative density than that by SLM method. Also, porosity of EMB fabricated parts lees than in SLM fabricated parts. The mechanical properties of parts manufactured by EBM have shown better results than the SLM fabricated parts and are quite similar to that of conventionally fabricated parts [12].

Taheri et al. through his research on A M methods states that each material forming process has characteristics associated with the incident heat source; material feed stock and material transfer mechanism which combine to affect the physical properties of the fabricated parts [13].

Harun et al. in his study of SLM used to produce biomaterial for dental and medical purposes states that SLM can be incorporated to produce biomaterials using 316L stainless steel, pure titanium, titanium, cobalt and aluminum alloys. However, the properties of these biomaterials depend on the processing parameters and design of them. The study also states that SLM method is used to improve the mechanical properties and fabricated complex structures which are quite difficult to attain by conventional subtractive manufacturing [14].

Fu et al. studied the fabrication of NiTi alloy through micro- SLM method. Through experiments he found out that mechanical properties such as compressive strength and fracture strain are 2796.57 and 27.80 % respectively, which are higher than that of other methods. The brittle phase of the alloy is addressed by using post processing heat treatments which again results in inhomogeneous microstructure and lower ductility [16].

Cardaropoli et al. discussed the correlation between the main process parameters in SLM. He states through his study that SLM can be used to build medical implants with the desired mechanical properties and the residual porosity [17].

Read et al. observed through his experiments that the building direction doesn't have a significant influence on the nature and the properties of the finished products. Parts fabricated by both directions by SLM have shown higher strength by parts developed in die cast A360 but the elongation was found to be inferior than the parts fabricated by A360 [18]. Moreover, the study also shows that the fracture surfaces are results of the presence of significant amounts of un- melted powder, which leads to rise of local cracking [18].

Tuck et al. through his work states that particle size SLM material powders make a great influence in distribution of the molten material into layers. He also concludes that powders with wider range of particle size results in higher powder bed density and relative density under low intensity lasers and also generates smoother side surfaces of the parts. However, narrower range of particle sizes of powder results in better flowability, ultimate tensile strength and hardness of the parts manufactured [19].

Liao et al. observed through experiment on SLM fabricated part of aluminum that the relative density is influenced by the scanning speeds and the hatching distances of the particles of the material grains. The relative density of the material increases with the increase in hatching space and scanning speeds [20].

Banmg et al. in his work on the influence of processing parameters on the mechanical properties of the SLM fabricated part observed that the hardness of the parts increased and the strength and elongation decreased as the energy density of the beam increased. Also the brittleness of the parts increased with the increase in the energy density of the beam, which is because of increase in the oxygen content [21].

## V. CONCLUSION

Additive manufacturing is a technology which is quite opposite to the conventional subtractive manufacturing processes. The need of AM arouse as researchers felt the need of a manufacturing method to build multiple prototypes in a short span of time and cost effectively so that the building time and cost doesn't hamper their research work. From that initial stage a lot of advancement has been made in this field. There are several different types of methods of AM developed to serve different purposes with the same basic principle of building parts by adding materials and not subtracting them. Selective Laser Melting is one of the methods which are getting very prominent, gradually in the manufacturing industry. The SLM uses a high power laser beam to melt material in the powder form and this molten material is added layer by layer to built the desired shape and size of the part. There are lots of factors influencing the SLM process from processing parameters, fabrication environment to the bulk and powdered material properties. Following are the major conclusions outlined from the study-

- High accuracy, functionality, minimal post-processing, wide variety of materials, allows the creation of complex and unique shapes from metal powders, surface structuring and high recyclability of the raw material are some of the most important advantages for which SLM is incorporated into the manufacturing industry
- Other than the processing parameters, there are few other phenomena such as the absorptivity of irradiation the powdered material, balling effect and the thermal fluctuations which greatly impact the fabrication process through SLM.
- The processing parameters having impact on the SLM process are classified into laser dependent parameters and builds dependent parameters. Scanning power, scanning velocity and scanning strategy, spot size and hatch distance are the laser dependent parameters, whereas layer thickness, build orientation, build temperature and inert gas of the building chamber are the build- dependent attributes.
- The SLM process is carried out in no or limited oxygen or in presence of inert gases, as it is used mostly to fabricate metal parts and fabrication in presence of oxygen develops oxides of the metal used.
- Mechanical properties of fabricated parts such as relative density, hardness, tensile strength, microstructure of the part influence greatly in the material selection for SLM. The processing parameters also have a significant impact on these mechanical properties.
- The grain refinement or finer grain sizes of the powder increases the tensile strength of the parts. Finer grain structure can be attained by having a higher temperature gradient.
- The brittleness of top surfaces of the layers can be treated by in- situ heat treatment, where heat from molten metal of the next layer is used to heat the previously solidified layer.
- The porosity of fabricated parts from SLM is better than that of parts fabricated by SLS and EBM.
- The relative density of a fabricated part generally increases with the increase in laser power. Also better relative density can found in parts having hatch distance of 0.1 to 0.15. It also increases with the increase in hatching distance and scanning speeds.
- SLM has a vast application in the dental and medical industry as complex structures can be built with ease. The materials used are most commonly metal such as alloys of steel, titanium, aluminum etc with few composites and ceramics. The most common grade of steel is the 316 L stainless steel.
- Metal powders with wider range builds parts with higher relative density at low laser power and powders with narrower range builds parts with better tensile strength and hardness.

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