Comprehensive Study of Additive Manufacturing and the Selection of appropriate method in manufacturing of Functionally Graded Materials (FGM)

[1] Sainath.K , [2]Dr. Prabagaran.S

[1]Research Scholar (Author)

Department of Mechanical Engineering

Karpagam Academy of Higher Education

sainath0318@gmail.com

[2]Associate Professor (Co-Author)

Department of Mechanical Engineering

Karpagam Academy of Higher Education

s.prabagaran.cbe@gmail.com

Abstract: It is assumed that using Additive Manufacturing only production of microscopic parts is possible and layer-based additive manufacturing methods can't make large components and large quantity of items. This study focuses on large-scale additive manufacturing using commercially available equipment’s and additive manufacturing technologies. This article also seeks to promote the design and development of an alternative additive manufacturing technology methods with Functionally Graded Materials by creating a rational framework. Various mechanical properties of alloys manufactured using Additive Manufacturing is studied and the results are compared with properties of alloys manufactured using conventional manufacturing methods. Detailed step by step process of AM is evaluated

in this article, with its application and the impact in the properties of material because of modification in process parameters are also reviewed.

Keywords: Additive Manufacturing (AM), Powder Metallurgy, Functionally Graded Material (FGM), Directed Energy Deposition, Design for Additive Manufacturing (DFAM), Titanium.

1. Introduction

Additive manufacturing (AM) of functionally graded material (FGM) objects has garnered significant research interest in the last decade. FGM parts printed using additive manufacturing are finding innovative usages in numerous applications. To move from research sample and prototypes to commercially viable functional FGM parts, it is necessary to develop an integrated approach for modeling, optimization, and process planning for AM fabricated FGM parts[1]. While solid modeling of FGM objects has been studied in detail, the build orientation optimization and process planning for AM fabricated FGM objects remain largely unaddressed. The build orientation of FGM object can significantly influence overall print quality and cost [1].

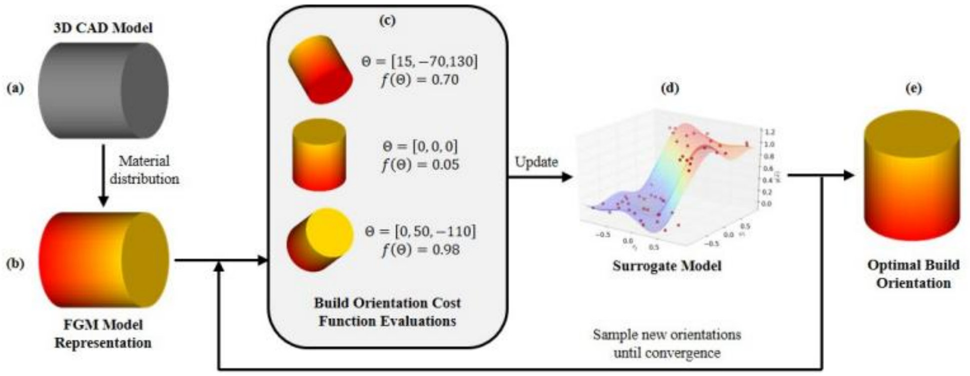

Fig 1: FGM Optimization Process using Additive Manufacturing[1]

Parts are created using tools in traditional manufacturing. Because these instruments are costly, and the return on investment is also connected to the number of parts produced, conventional manufacturing is best suited only for mass production [2]. Such tools require a significant amount of effort and money to develop.These tools are utilised in procedures like as injection moulding, pressure die casting, and press tools [3]. AM does not necessitate the creation of such tools. Even if the components are complex, they can be made in small quantities and with proper process planning can be extended to large quantity manufacturing. The best applications for additive manufacturing are prototype development and small batch production [4]. Table 1 shows the properties of different metals manufactured using additive manufacturing.

Table 1: Mechanical Properties of different materials fabricated using additive manufacturing [4].

Material grade		Stainless Steel 1.4404	Tool Steel 1.2343	TiAl6V4
Tensile Strength	MaP	480-520	780 - 840	1200-1400
Elongation	%	10-15	2-3	1-2
Hardness	HB	220-250 HV0.1	50-54 Rockwell	380-420 HV0.3
Surface finish	µm	Rz 30 – 60 µm	Rz 30 – 60 µm	Rz 30 – 60 µm
Accuracy	+/- mm	<0.1 mm	<0.1 mm	<0.1 mm
Maximal work-piece size	X; Y; Z mm	n.a.	n.a.	n.a.
Density of parts	%	ca. 100%	ca. 100%	ca. 100%
Production rate	mm^3/hr	n.a.	n.a.	n.a.

In the AM, a three-dimensional solid model created in CAD software serves as the input. This three-dimensional CAD model is divided into layers geometrically.The segmented information is stacked as two-dimensional sections to produce the final product. The AM can significantly shorten the product development cycle's lead time. When compared to the typical material removal technique, the component can be created in a very short period by using the AM slicing procedure. The fundamental advantage of the additive manufacturing process is that even complex parts may be made with minimal human input. As a result, the entire lead time in the product development cycle is reduced. Additive manufacturing is used in a variety of sectors. Furthermore, there is a lot of potential for employing additive manufacturing to directly build huge functioning parts. Manpower is still employed in the construction of massive constructions due to their size. The most recent layer-based manufacturing techniques are limited to large components [5]. There are numerous research opportunities for accelerating the build time of additively made components; the same approach can also be employed for creating huge components.

The Additive Manufacturing (AM) sector is experiencing a period of rapid expansion. Additive Manufacturing (AM) is a range of technologies that converts a CAD file into a physical component by depositing material layer by layer to create the desired item [6]. It is the opposite of the traditional method of material removal, in which material is removed from a solid stock to create the required part.

Numerous unimaginable results are detected because of the AM Technology virus epidemic [7].Among these include the production of metal components, bioprinting, multi-material printing [8].

2. Literature Review

The use of pure metals or alloys in modern engineering has been greatly reduced since they fail to match the criteria and complexity of built structures. To address these needs, novel material combinations based on metals, polymers, ceramics, and so on are developed. FGMs are advanced composites that are manufactured to achieve the desired qualities in an engineered construction or application [9]. There are works which exemplifies the development of metal-metal (Al-Cu) functionally graded materials (FGMs) using powder metallurgy and sintering. An Example of Al-Cu FGM is studied in this article using an Additive Manufacturing process.

2.1 Development of Al-Cu FGM

Various manufacturing methods for FGMs are categorised into three broad categories: gas-based methods, liquid phase processes, and solid phase processes. Based on a review of the literature, the specimen for this study was created using one of the solid phase methods, namely powder metallurgy.

2.2 Powder Metallurgy

Powder metallurgy (PM) is a method of solid-state manufacturing. It begins with the reduction of metal ingots to powder, followed by the blending of the powders and the production of finished or semi-finished items with or without the addition of non-metallic elements and additives[10].

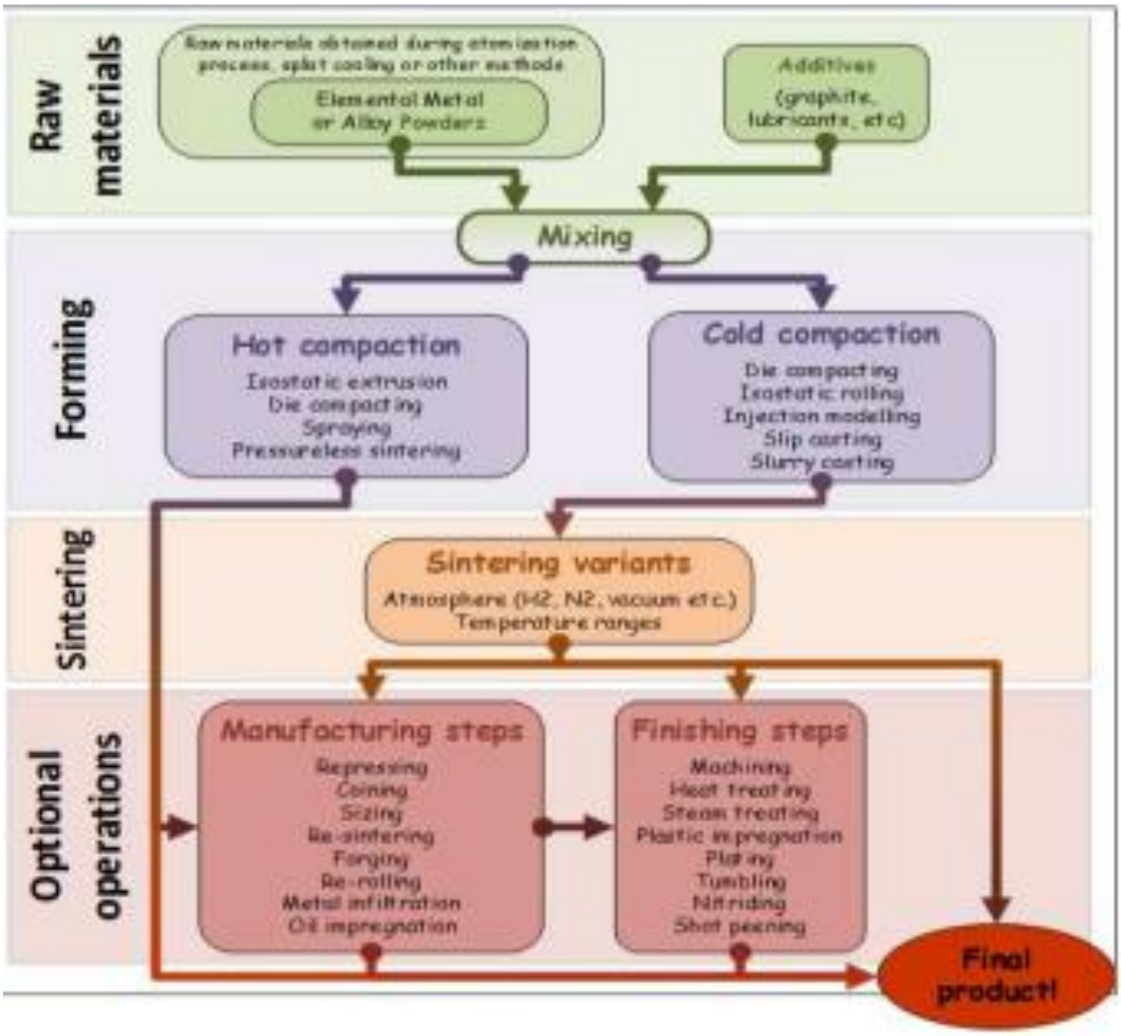

Fig 2: Powder Metallurgy Process for a Functionally Graded Material[10]

The fine powdered components are combined, compacted into the appropriate shape, and then heated in a controlled environment, known as sintering, to assist the bonding of powder particles into a final product. As seen in Figure 2, the PM process consists of four main steps: powder blending or mixing, compaction, and sintering. Optional secondary machining or finishing procedures are available. A compaction tool forces the metal mix's powder together, followed by sintering the powder particles together into a solid mass using a combination of pressure and heat without melting the mix. Compacting is done at high pressures and at room temperature, whereas sintering is done at air pressure and at high temperatures. Sometimes the sintering and compaction processes are combined. [10]

The optional secondary procedure of machining or finishing produces superior dimensional precision and improved characteristics. The powder metallurgy technique can produce single or multiple materials, such as FGMs, with high strengths and integrity. [11] The classification of metallic and non-metallic powders in powder metallurgy is given below in the Table 2.

Table 2: Classification of Present Powder Metallurgy Application [12]

Metallic and Non-Metallic Powders		
Sintered parts production	**Direct Application**	**Special and new advance, material protection**
• Structural parts • Auto lubricating parts • Sintered parts from special materials	• Magnetic powders for copiers, non-destructive inspection, magnetic fluids • Powders for agriculture and food industry • Powders for colorants • Abrasive Powders • Particulates reinforcing components for composites • Powders for coatings (spray deposition) • Powders for welding electrodes • Powders for flame cutting • Powders for biomedical applications • Powders for optical applications	• Materials of high melting points • Composite materials • Particulate reinforced of metallic and intermetallic matrix • Friction materials • Wear resistant materials • Corrosion resistant materials • Refactory materials • Porous materials • Materials for electro-techniques • Magnetic materials • Tool matetrials • Heavy alloys • Nano crystalline/amorphous material

2.2.1 Powder Manufacture

The quality of the final product is based on the qualities of the powder; therefore, it is essential to test the powder's quality during the process of manufacturing the powder, characterising the powder, and treating the powder. Different manufacturing processes for powders include:

a. Atomising Process

b. Gaseous Reduction

c. Electrolysis Process

d. Carbonyl Process

e. Stamp and Ball mills

f. Granulation Process

g. Mechanical Alloying

h. Other methods (production of fine metals by machining, precipitation from a chemical solution and vapour condensation.)

2.2.2 Powder Blending or Mixing

In certain applications, a single, homogeneous metal powder may not be able to provide all the necessary mechanical qualities; instead, FGMs generated by powder metallurgy with custom-tailored mechanical properties are mixed or blended to create the final product. There are a lot of reasons why various powders are combined or blended. [13]

a. Powder particles can be uniformly distributed to achieve homogeneous shape using the blending process,

b. Blending enables mixing of dissimilar powder particles to achieve the widespread mechanical and physical properties,

c. Lubricants or additives may be added through the blending process which reduces friction between dies and powder particles, in the direction of improvement in flow characteristics of the powder particles.

d. Green strength can be enhanced by adding the binders to the mixture of the powder particles during the process of compaction. [13]

2.2.3 Compaction

In the process of compaction, pressure is employed to bond and cohere powder particles. This procedure is performed to achieve a green strength between powder particles. The compaction method achieves the following results. [14]

a. Voids are reduced between the particles of powder and combined powder density is enhanced.

b. Between the powder particles, bonding and adhesion is produced which in turn improves the green strength of the combined powder particles,

c. Powder particles aid in plastic deformation which helps in conforming the parts to the desired shape.

d. Contact area between the particles is increased which aids in the next process of sintering

As the compaction pressure increases the hardness increases because of decrease in the porosity of material and is shown in the figure 3.

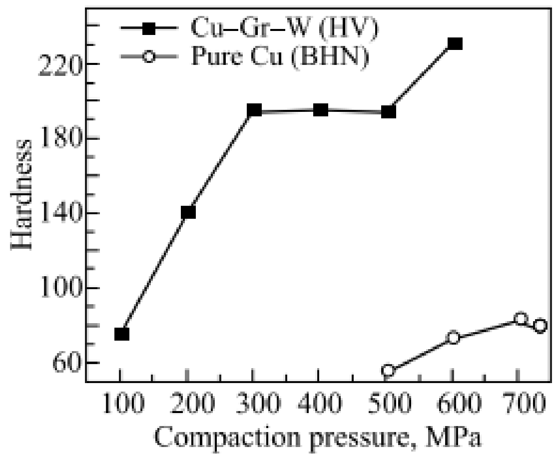

Figure 3: Impact of hardness value because of variation in compaction pressure [14]

In the process of compaction, a measured amount of metallic powder is poured into the die cavity, followed by the application of pressure with a punch or plunger. The application of compressive force by the punch or plunger from both the top and bottom confirms consistent pressure distribution, resulting in minimal porosity in the specimen. Initial particle shape, specific particle features, blending processes, and application of lubricants are some of the variables that influence the applied pressure for compaction[15] Extremely dense metallic particles are difficult to compact. Organic binders are employed to hold hard metallic powders together until the sintering process is complete [16]

2.2.4 Sintering

In the process of compaction, pressure is employed to bond and cohere powder particles. A specific temperature is applied to compacted metallic powder during the sintering procedure lower than the melting point temperature of standard powder particles however beyond the temperature that permits diffusion between the powder particles). During the sintering process, different powder particles are fused together, which increases the strength of the completed components. During sintering, oxidation might occur if a regulated atmosphere is not established. During the production of extremely critical parts, the sintering process is conducted in a vacuum, a reducing environment, or the presence of an inert gas to prevent oxidation. [17]

The Hardness of material increases with increase in sintering temperature, but after a threshold limit it doesn't increase beyond as shown in Figure 4 [18]

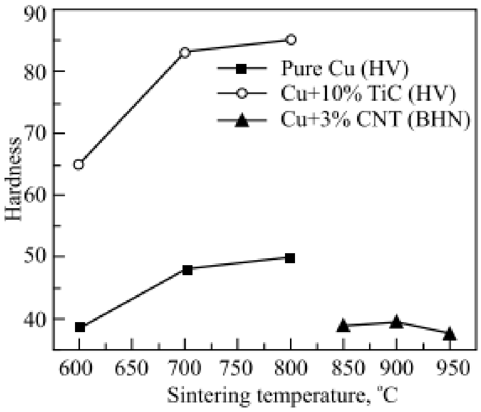

Figure 4: Impact of hardness value because of variation in compaction pressure [18]

After the process of compaction, compacted powder is brittle and has limited green strength. The elements that influence the strength of compacted components are the diffusion process, volatile material evaporation in the compacted preform, and the plastic flow characteristic of particles. The melting of small components presents in the powder, the diffusion process between the particles, and mechanical bonding are the three mechanisms of particle adhesion. Temperature, time, and the environment of the furnace are the crucial governing variables for sintering. Due to the filling the original holes and the increased contact area between the particles in the compressed preform powder, the end part's density is raised during the sintering process. To improve the quality of the final component, finishing operations such as re-pressing (to ensure dimensional accuracy), heat treatment, and machining are performed following the sintering process. [19]

2.3Additive Manufacturing Strength

In this study, a new AM system is constructed and evaluated, therefore the input data must be trustworthy. The result of strength achieved is studied using various additive manufacturing process and Laminated Object Manufacturing has the highest strength followed by 3D printing which has the lowest strength. [20]

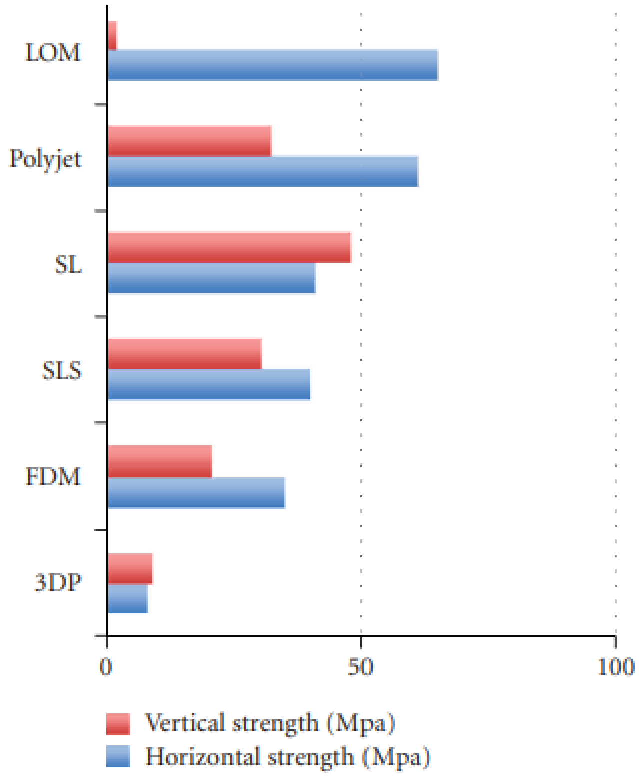

Figure 5: Strength Comparison of Various additive manufacturing technique [20]

The Strength of various materials manufactured using additive manufacturing process is studied and any alloy/material with presence of titanium gives the highest ultimate tensile strength and yield strength. The below figure 6 shows that the Titanium alloys has the highest strength.

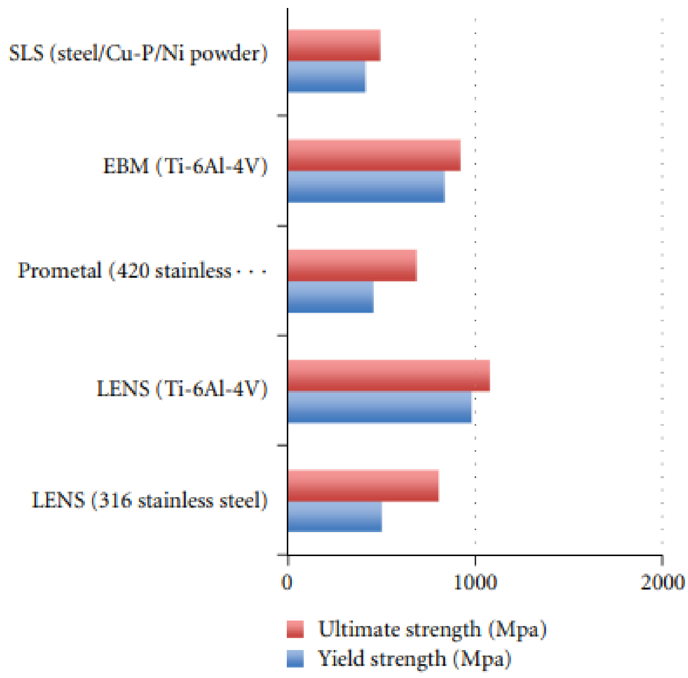

Figure 6: Strength Comparison of Various materials using additive manufacturing technique [21-25]

3. Problem Statement

Additive Manufacturing (AM) manufactures products from digital models. Many studies support AM for big components [2]. Commercial additive manufacturing equipment can make large parts, but production is limited.Also, Traditional AM methods produce only single structure material. Massive components require Additive Manufacturing Technologies. As the component size increased, layer-wise fabrication had lower productivity. A low-cost, rapid additive manufacturing solution is needed [26]

Human life relies greatly on materials, both for daily use and engineering and technology advances. The Stone, Bronze, and Iron Ages were all named after materials. Engineering and technical progress are impossible without materials. For technical applications, it's vital to examine materials and fabrication procedures. Choosing a material that optimizes system performance is key to a well-built and optimized design. [27]

Natural and manmade materials can be grouped, as can pure metals and alloys. Until recently, the depletion of conventional supplies and the necessity for materials with different mechanical qualities limited the use of pure metals in engineering. Alloys are limited by the solubility of their elements. To meet the technical challenges of the 21st century, scientists and researchers have invented new classes of materials called Functionally Graded Materials which combines different property of materials in a single structure. To manufacture the FGM recent additive technologies needs to be evaluated to find the best method.

4. Methodology

4.1 Processing of Additive Manufacturing

Additive Manufacturing is in the growth phase as a global technology. When its application areas are analysed, they are largely used in motor vehicles and consumer products. Figure 7 explains the different real time applications in pie chart.

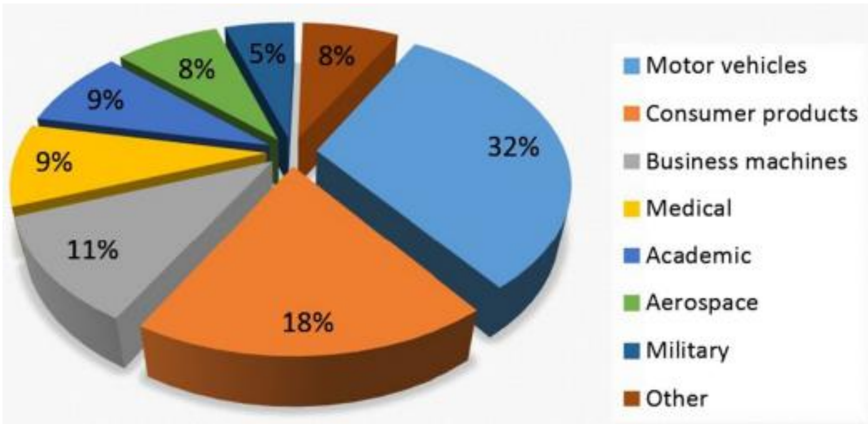

Figure 7: Pie-Chart of Real Time Applications of Additive Manufacturing [28]

4.2 Design Optimization of Additive Manufacturing

Design rules are very much important since we need to analyse the product based on the design requirements. Enough modifications need to be done in the design so that it is suitable for additive manufacturing. Design Optimization and ratings is done based on the design optimization. Methodology used for this purpose is called Design for Additive Manufacturing (DFAM).

Table 3: Design Optimization using Additive manufacturing Technique [29]

category	criteria	A	B
Property improvement of part through **design optimization**	Is a design optimization (e.g. topographic optimization) possible / needed?	3	3
	How is the potential of possible weight reduction?	3	3

	design optimization	weight reduction
	design optimization due to AM manufacturing process (e. g. topographic optimization)	based on past experience of AM experts, a first, rough estimation of the possible weight reduction / safety factors need to be considered
1	-	-
2	part already optimal designed for loads	none
3	design optimization possible but not needed, because the effort for design change does not justify the possible gain / e.g. for Case A parts	<10 % weight reduction compared to original design
4	potential for design optimization possible and also required	11-20 % weight reduction compared to original design
5	big potential for design optimization possible and strongly required / e.g. mainly for Case B parts	>20 % weight reduction compared to original design

As per Figure 8 there are 8 different key aspects to be checked while using the Additive Manufacturing Technique. In this key aspect all the activities need to be properly maintained for a perfect design and for a effective cost effective solution. [30]

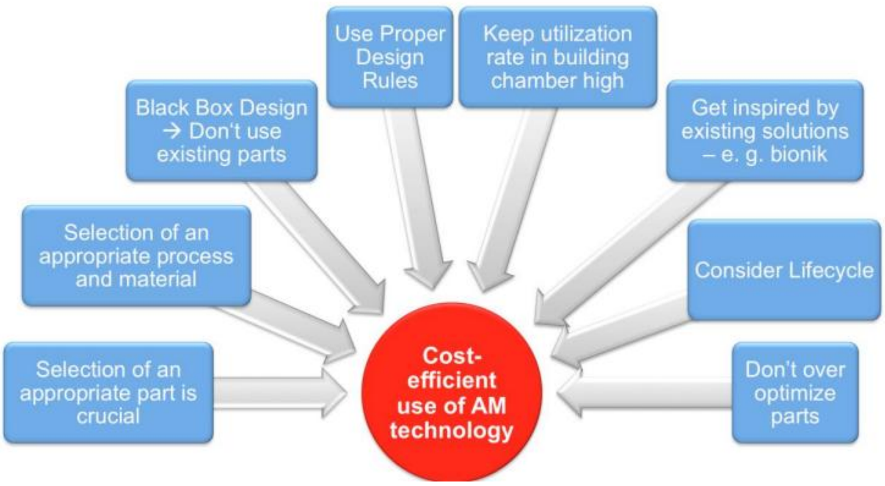

Figure 8: Key aspects for Cost Effective Additive Manufacturing Solution [30]

5. Comparative Study of Additive Manufacturing

The Additive Manufacturing (AM) sector is experiencing a period of rapid expansion [6] virus epidemic [7]. Among these include the production of metal components, bioprinting, multimaterial printing, and 4D printing [8].

Additive Manufacturing or Freeform Fabrication is a range of technologies that converts a CAD file into a physical component by depositing material layer by layer to create the desired item [6]. It is the opposite of the traditional method of material removal, in which material is removed from a solid stock to create the required part.

The following are the advantages of Additive manufacturing process over the conventional material removal processes [31].

1. Less or no post processing required when compared to the conventional manufacturing processes.
2. There is lot of emerging possibility in the usage of materials in AM.
    a. The recent AM process offers lot of material varieties and the user is allowed to tailor-make the material.
    b. The material wastage and scrap is almost zero.
    c. The material ranges from plastics to metal.
3. There is a lot of design freedom associated with the parts that are manufactured. The components with complex design which are difficult to manufacture can be easily manufactured through AM.
4. There is very using AM.
5. Additive Manufacturing suits manufacturing of low volume in a very economical way when compared to the traditional manufacturing [31]

The Additive Manufacturing Techniques are also classified based on their process type as per Table 4.

Table 4: Additive Manufacturing Process Based on Process type [31]

Additive Manufacturing (AM) Processes							
Process	Laser Based AM Processes: *Laser Melting*		Laser Based AM Processes: *Laser Polymerization*	Extrusion Thermal	Material Jetting	Material Adhesion	Electron Beam
Process Schematic	Laser source, Powder bed	Laser source, Powder supply	Laser source, Liquid resin	Material melt in nozzle	Material jetting	Laser cutting, Compactor	Electron beam, Powder bed
Name / Material	SLS	DMD	SLA	FDM	3DP	LOM	EBM
	SLM	LENS	SGC	Robocasting	IJP	SFP	
	DMLS	SLC	LTP		MJM		
		LPD	BIS		BPM		
			HIS		Thermojet		
Bulk Material Type	Powder		Liquid	Solid			

There are a variety of reported technologies. According to ASTM F42 on Additive Manufacturing, the AM processes can be categorised into seven groups. This is depicted in Figure 9. It also classifies this seven Additive Manufacturing process by related technology and few examples of the companies used.

Figure 9: Additive manufacturing methods based on [32]

Table 5: Classification of Additive Manufacturing Technique based on Related Technology [33]

Process types	Brief Description	Related Technology	Companies	Materials
Powder Bed Fusion	Thermal energy selectively fuses regions of a powder bed	Electron beam melting (EBM), selective laser sintering (SLS), selective heat sintering (SHS), and direct metal laser sintering (DMLS)	EOS (Germany), 3D Systems(US), Arcam (Sweden)	Metals, Polymers
Directed Energy Deposition	Focused thermal energy is used to fuse materials by melting as the material is being deposited	Laser metal deposition (LMD)	Optomec (US), POM (US)	Metals
Material Extrusion	Material is selectively dispensed through a through Nozzle or orifice	Fused deposition modelling (FDM)	Stratasys (Israel), Bits from Bytes (UK)	Polymers
Vat Photo polymerization	Liquid photopolymer in a vat is selectively cured by light-activated polymerization	Stereo lithography(SLA), digital light processing (DLP)		Photopolymers
Binder Jetting	A liquid bonding agent is selectively deposited to join powder materials	Powder bed and inkjet head (PBIH), plaster-based 3D printing (PP)	3D Systems (US), Ex One (US)	Polymers, Foundry Sand, Metals
Material Jetting	Droplets of build material are selectively deposited	Multi-jet modelling (MJM)	Objet (Israel), 3DSystems (US)	Polymers, Waxes
Sheet Lamination	Sheets of material are bonded to form an object	Laminated object manufacturing(LOM), ultrasonic consolidation (UC)	Fabrisonic (US), Mcor (Ireland)	Paper, Metals

5.1 VAT Photopolymerization

A tank of photopolymer liquid is used in the VAT Polymerization technique. A photopolymer is a liquid resin that reacts to visible or ultraviolet light. When exposed to light, the liquid resin undergoes physical changes such as material hardening owing to interlinking. Only a little portion of the liquid's top surface is exposed to a powerful ultraviolet light during this procedure, and the liquid that is exposed to the light alone is cured and hardened[34]. To shave and flatten the top surface, a moving knife edge is used. This allows printing of the next layer and ensures correct layer bonding. The default layer thickness is used to reduce the top surface to the next level. This operation is repeated until the photopolymer liquid hardens and is placed layer upon layer, yielding the final output. A liquid medium is used in the procedure, as well as an auxiliary support structure made of the same material to support the overhanging areas of the part. A motorised mirror directs the ultraviolet light source[34]. The mirror is connected to two motors that rotate it along two perpendicular axes, allowing light to be reflected in two directions with two degrees of freedom. Acrylonitrile butadiene styrene (ABS) r4esin, Polyphenylene Ether (PPE) resin, and Glass-Filled Nylon Resin are some of the popular materials utilised in this procedure [35], Liquid-Based Rapid Prototyping Systems, 3D Systems' Stereolithography Apparatus (SLA), Cubital's Solid Ground Curing (SGC), D-Solid MEC's Creation System (SCS), CMET's Solid Object Ultraviolet-Laser Printer (SOUP), Teijin Seiki's Soliform System, Autostrade's E-Darts, Rapid Prototyping System for the Jewelry Industry, Digital Light Processing (DLP) (DLS). Schmidt and colleagues (2017)

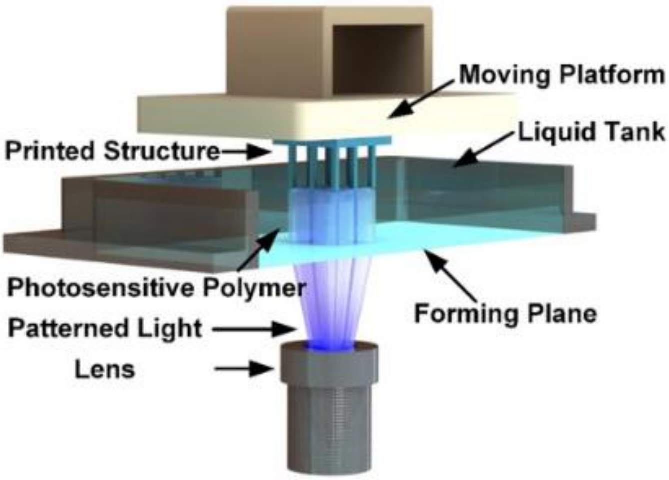

Figure 10: VAT Polymerization Process [36-38]

5.2 Material Jetting

The material jetting method is like that of inkjet printing. The material to be deposited is sprayed through a jet inside the designated region. The substance is sprayed either drop-on-demand or continuously. Allow the sprayed substance to harden. After that, the platform is lowered by one-layer thickness. This technique is repeated until the entire component or product's material has been deposited. The nozzle is moved horizontally by a linear drive across two axes. After a layer has been entirely deposited, the part is cured with an ultraviolet light source[39]Because this procedure uses a drop-on-demand method, the materials available are limited to polymers and waxes. The binder jetting procedure uses two types of materials: powder and an adhesive that selectively binds the powder. The glue is in the liquid state. The first print head deposits powder material, while the second print head deposits liquid glue. The platform is then lowered by measuring the thickness of a layer, and the procedure is repeated until the complete section is produced.Material Jetting pieces are not structurally strong because they are created layer by layer utilising a power adhesive combination. Polypropylene, High-density polyethylene (HDPE), Polyamide (PA), Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), High Impact Polystyrene (HIPS), Polystyrene (PS), and Polymethyl methacrylate (PMMA) are some of the most often utilised polymers in material jetting [31]Polyjet Printing (PJ), Object, Material Jetting, Nano particle jetting (NPJ), and Drop-On-Demand (DOD) are some of the technologies [39].

5.3 Binder Jetting

Two components are fed into the binder jetting process. The first material is in powder form, while the second is in liquid adhesive form. A print head or roller moves horizontally along two axes, depositing a layer of the build material, which is a powder-based material. The print head then selectively deposits the liquid-based glue where the power-based substance joins together. The bed is lowered by one-layer thickness, and the alternate deposition process is repeated until the entire portion is constructed. The created pieces are suitable for aesthetic study and display, but they are not structurally sound and cannot be utilised as working parts. 3D Printing is another name for this technique (3DP). Post-processing takes a significant amount of time[40] Stainless steel, polymers such as ABS, polyamide, polycarbide, and ceramics such as glass are some of the usual materials that can be utilised in this procedure. 3D printing is one of the most common commercially available technologies (3DP).

5.4 Material Extrusion

A material wire spool is passed through a nozzle, which heats, melts, and deposits the wire material in the desired region. The nozzle is regulated to move horizontally along two axes using servo control motors. Once the material has been deposited in the specified location, the platform is lowered to one-layer thickness and the procedure is repeated to deposit layers of material to build the finished component[41] The various hanging positions of the part must be supported by support structures. Another wire spool serves as the feed for printing the water-soluble support material. The completed portion is immersed in water with ultrasonic vibration to dissolve the support material. The component's strength varies along the print direction and perpendicular to the print direction. Fabricated components can be utilised for visual prototypes and investment castings[41].This approach also produces parts that are unsuitable for functional useABS, Nylon, and Polycarbonate are some of the popular materials that can be used in this technology to manufacture parts. Fused Deposition Modelling (FDM) and Fused Filament Fabrication (FFF) are two prevalent technologies (F42 Committee 2009).

Different types of material extrusion process is shown in below figure 11,

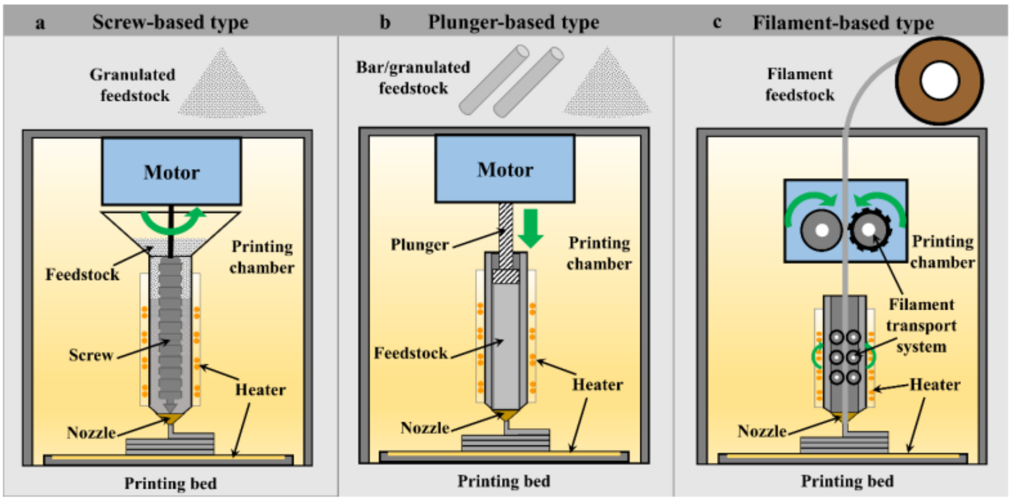

Figure 11a) Screw based type material extrusion

Figure 11b) Plunger based type material extrusion

Figure 11c) Filament based type material extrusion [41]

5.5 Powder Bed Fusion

A laser beam is used to fuse a layer of powder bed along a specified area to form the cross section of a part. With the use of rollers, a layer of powder is applied to the platform. A laser beam or an electron beam is used to fuse and solidify a specific area. The platform is lowered, and the next layer of power is distributed, and the procedure is repeated until the section is completed. This procedure uses a wide range of materials. Metal powder can also be sintered to create pieces [42-45].The powder bed itself works as a support for the part's overhanging sections. As a result, different support systems are unnecessary. Because the cooling rates for the sintered solid section and the un-sintered powder bed differ, there is a high possibility of warpage and sagging of the finished component's overhanging regions. The powder bed fusion approach can produce fully functional pieces. Materials such as stainless steel, titanium, aluminium, and cobalt chrome can be used to make components utilising this process. Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Direct Metal Laser

Sintering (DMLS), Electron Beam Melting (EBM), and Multi Jet Fusion (MJF) are some of the common technologies available (F42 Committee 2009)[42-45].

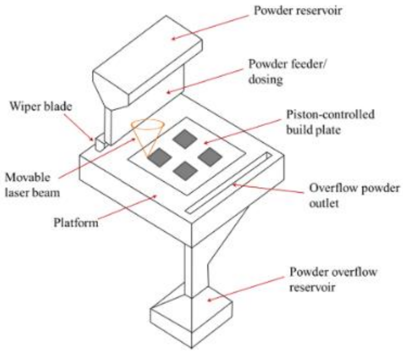

Fig 12: [42-45]

5.6 Sheet Lamination

Sheets of material are used as raw material in this technique. The outline of the cross section is cut with a knife edge or a laser. To make the finished component, the cross pieces are fused together with adhesive or ultrasonic welding. From paper to metals, a wide range of materials can be employed. Outside the outline of the cross section of the part itself, the sheets act as a support for the overhanging areas. To facilitate removal, the outer sheets are sliced into smaller pieces using a laser or cutting edge. There is no need for additional support structures. Some disadvantages include the need for extensive post-processing, the difficulty of removing extra portions that do not belong to the final part, the waste of a large amount of material in the process of providing support structures, and the strength of the component varying along different directions. This method can be used to create concept design prototypes. Sheet metal, paper, and plastic are some of the materials that can be used. Laminated Object Manufacturing is one of the most popular technologies that fall within the Sheet Lamination category (LOM). Additive Manufacturing Using Ultrasonic (UAM). Kira's Paper Lamination Technology (PLT) produces components that are best suited for visual presentation and cannot be used as functional parts [46].

5.7 Direct Energy Deposition

The machine is made up of a material wire spool. The wire is passed through the nozzle, and as it exits the nozzle, it is melted with a laser or electron beam source. The nozzle is controlled by five axes, two of which are rotating. Material can be deposited from any angle. Materials ranging from polymers to metals can be employed. This approach can be used to fix metal components that are unrepairable using traditional methods. This process can also be used to strategically add characteristics to conventionally manufactured castings and forgings. The goods made utilising the DED process have excellent material and mechanical qualities. These material qualities, together with the process's robustness, greatly reduce overall manufacturing costs. Metals, rather of polymers or ceramics, are employed to make parts utilising this technology, including Cobalt Chrome and Titanium. Direct Metal Deposition (DMD), 3D laser cladding, Laser designed net shaping, directed light manufacturing, and Electron Beam Additive Manufacturing are some of the technologies that utilise Direct Energy Deposition (EBAM). This approach is only applicable to Cobalt Chrome, Titanium, and Tantalum. Plastics, ceramics, and glass cannot be used in this approach. As a result, the usage of Direct Energy Deposition is limited to the automotive and aerospace industries [47-49]. The classification of Directed Energy Deposition in given in Figure 13.

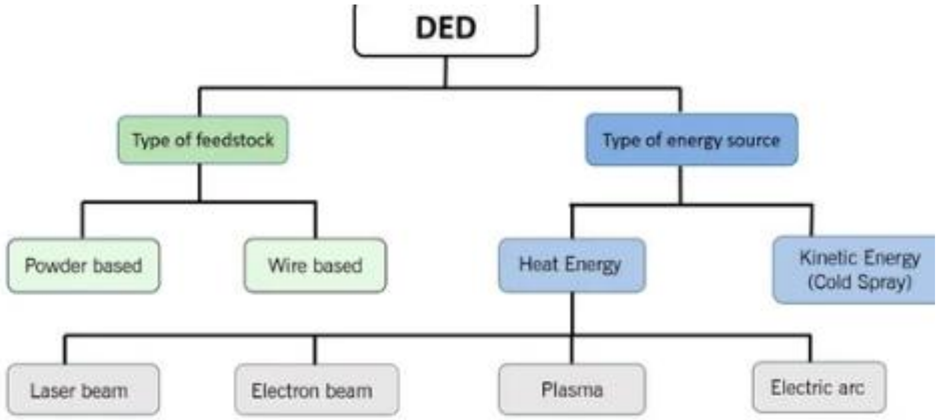

Figure 13: Directed Energy Deposition Classification [47-49]

As an overall consolidation the total additive manufacturing process is classified as in below figure 14.

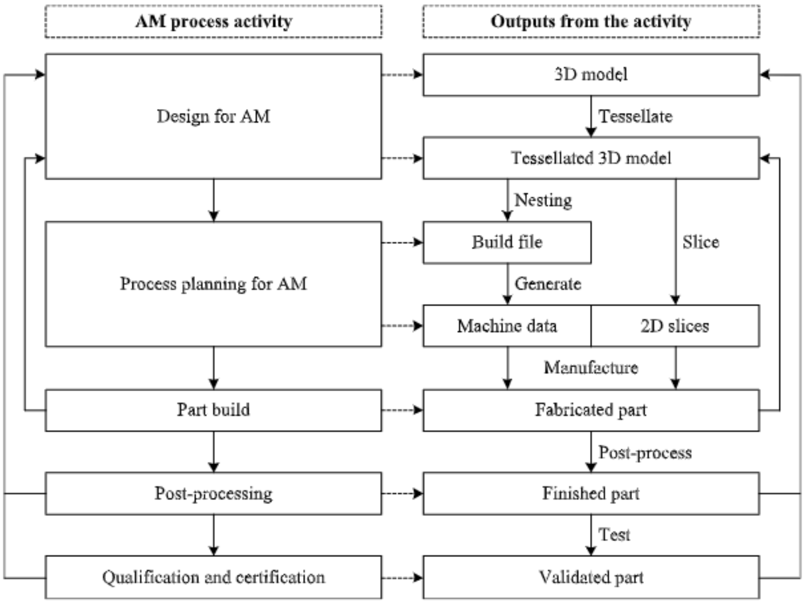

Figure 14: Step by Step Process of Generalized Additive Manufacturing [50]

6. Parameter Comparison of Additive Manufacturing Vs Conventional Manufacturing

The Detailed Comparison of Conventional Manufacturing verses Additive Manufacturing is provided in the below Table 6.

Table 6: Comparison of Parameters in Conventional Manufacturing Vs Additive Manufacturing [51]

S.no	Parameter	Conventional Manufacturing	Additive Manufacturing
1	Volume of manufacturing	High	Low
2	Design Methodology	Design for Manufacturing / Design for Assembly	Design for Additive Manufacturing
3	Complexity in shape	Low	High
4	Cost	Low	Medium
5	Fixture and Tools Requirement	More	Less
6	Material Wastage	Less	High
7	Lead Time of Production	Less	High

Mechanical Properties of two important materials are analysed and they are compared in the Table 7.

Table 7: Comparison Table for Material Properties of Additive Manufacturing Verses Conventional Manufacturing [52-53]

S.no	Material	Property	Conventional Manufacturing	Additive Manufacturing
1	Stainless Steel 316L -	Ultimate Tensile Strength (Mpa)	500	700
		Yield Strength (Mpa)	200	400
2	Ti 6Al 4V	Ultimate Tensile Strength (Mpa)	1170	1100
		Yield Strength (Mpa)	1100	1000

Table 8: Comparison of Possibility of FGM Manufacturing using various Additive Manufacturing Technology

S.no	Process Description	FGM Manufacturing Possibility
1	Vat Photopolymerization	Low
2	Material Jetting	Low
3	Binder Jetting	Low
4	Material Extrusion	Low
5	Powder Metallurgy	High
6	Powder Bed Fusion	Medium
7	Sheet Lamination	Low
8	Direct Energy Deposition	High

Laser metal deposition (LMD), laser cladding (LC), etc. are all subsets of t technique [54-57]. Because the DED method permits the feeding rate ratio of two or more types of raw materials (wire, powder) to be regulated, or the control of the laser scanning approach, it has become the best AM process for manufacturing metal FGMs [58].

7. Conclusion

From the Designer and Manufacturer point of view all the latest manufacturing methods of Functionally Graded Materials are proposed and reviewed. The Impact of mechanical properties based on different types of additive manufacturing and is also compared with conventional methods. In the analysis of all the alloying elements Titanium is the element which has the highest Ultimate Tensile strength and Yield strength in the Functionally Graded Materials category manufactured using Additive Manufacturing. When the AM Process is evaluated using powder metallurgy with the Increase in sintering time and compaction time hardness value increases. When all the Additive Manufacturing process is studied Powder Bed fusion is the cleanest method and higher accuracy method for metal additive manufacturing process. The products manufactured using Powder Bed fusion methods has the highest structural Integrity parameters. When the Mechanical Properties of Conventional and Additive Manufacturing are compared the properties are almost the same in Stainless Steel and Titanium Alloys which clearly shows that Additive Manufacturing Technology has advanced with performance to Conventional manufacturing. When different Additive Manufacturing Technologies with possibility of FGM Manufacturing are studied during initial analysis it is found that Powder Metallurgy has the highest possibility of FGM different materials mixing, Direct Energy Deposition and Powder Bed Fusion are the methods which has the medium possibility of FGM Manufacturing. However, it requires further study and research to develop methods of FGM using additive manufacturing and arrive a cost-effective solution to finalize the additive manufacturing method to mix different materials.

References

[1] Prakhar Jaiswal, Jayankumarpatel, & Rahul Rai, “Build Orientation Optimization for additive manufacturing of functionally graded materials”

[2] Saengchairat, N, Tran, T & Chua, CK 2017, 'A review: additive manufacturing for active electronic components', Virtual Phys. Prototype, vol. 12, pp. 31–46

[3] Costabile, G, Fera, M, Fruggiero, F, Lambiase, A & Pham, D 2017, 'Cost models of additive manufacturing: A literature review', Int. J. Ind. Eng. Computer, vol. 8, pp. 263–283.

[4] Levy, GN, Schindel, R &Kruth, JP 2003, 'Rapid manufacturing and rapid tooling with layer

[5] manufacturing (LM) technologies, state of the art and future perspectives', CIRP Ann.- Manuf. Technol, vol. 52, pp. 589–609.

[6] Khoshnevis, B 2004a, 'Automated construction by contour crafting— related robotics and information technologies', Autom. Constr, vol. 13, pp. 5–19.

[7] Beyca Faruk, Gulsah, Islaim, “Additive Manufacturing Technologies and applications”, 2018

[8] Bailey, StoyanStoyanov, “Machine Learning for additive manufacturing”, 2007.

[9] Demir Gokhan, Barbara, “Additive Manufacturing of cardiovascular stents”, 2017.

[10] Pankaj Kumar Chauhan, Sabah Khan “FGM A review of modelling of material properties”, 2016

[11] Umamaheshwer Rao, Ranjith Kumar, Banu Prakash Reddy, Sanjay,“Powder Metallurgy Process”, 2018

[12] Caesar Humberto Ortega Jimenez, “Systematic Review of Powder Metallurgy”, 2020

[13] ShagilAkthar, Mohammad Saad, Misbah, “Recent Advancements in Powder Metallurgy”, 2018.

[14] Leandro_Bolzoni, “Sintering of Titanium alloys”, 2022

[15] Naveen Kumar,Ajaya Bharathi “Effect of Powder Metallurgy Process and its Parameters”, 2020

[16] M. Dixit and R.K. Srivastava, “Effect of compaction pressure on microstructure, density and hardness of Copper prepared by Powder Metallurgy route,” IOP Conf. Series: Mater. Sci. Eng., 377, 012209 (2018)

[17] M. Yusoff and Z. Hussain, “Effect of sintering parameters on microstructure and properties of mechanically alloyed copper–tungsten carbide composite,” Int. J. Mater., Mechan. Manufact., 1, No. 3, 283–286 (2013)

[18] W. Brian James, Book Chapter on “Powder Metallurgy methods and applications”, Volume 7, 2015

[19] V.T. Pham, H.T. Bui, B.T. Tran, V.T. Nguyen, D.Q. Le, X.T. Than, V.C. Nguyen, D.P. Doan, and N.M. Phan, “The effect of sintering temperature on the mechanical properties of a Cu/CNT nanocomposite prepared via a powder metallurgy method,” Adv. Nat. Sci.: Nanosci. Nanotechnol., 2, No. 1, 015006 (2011).

[20] Samuel RantiOke, Peter ApataOlubambi, “Powder Metallurgy of Stainless Steels and Composites”, 2019.

[21] Kaufui V. Wong and Aldo Hernandez, “A Review of Additive Manufacturing”, 2012

[22] P. P. Kruth, “Material incress manufacturing by rapid prototyping techniques,” CIRP Annals—Manufacturing Technology, vol. 40, no. 2, pp. 603–614, 1991.

[23] T. Wohlers, Wohlers Report 2009, Wholers Associates, 2009.

[24] J. W. Halloran, V. Tomeckova, S. Gentry et al., “Photopolymerization of powder suspensions for shaping ceramics,” Journal of the European Ceramic Society, vol. 31, no. 14, pp. 2613–2619, 2011.

[25] D. T. Pham and C. Ji, “Design for stereolithography,” Proceedings of the Institution of Mechanical Engineers, vol. 214, no. 5, pp. 635–640, 2000.

[26] A. D. Taylor, E. Y. Kim, V. P. Humes, J. Kizuka, and L. T. Thompson, “Inkjet printing of carbon supported platinum 3- D catalyst layers for use in fuel cells,” Journal of Power Sources, vol. 171, no. 1, pp. 101–106, 2007.

[27] Shuo Yin, Pasquale Cavaliere, Barry Aldwell, Richard Jenkins, Hanlin Liao, Wenya L i, Rocco Lupoi, “Cold Spray Additive Manufacturing Technique”, 2018

[28] UzairKhaleequz Zaman, Mickael Rivette, Ali Siadat, SeyedMeysam Mousavi “Integrated Product Design in Additive Manufacturing”, 2018.

[29] Kruth JP, Levy G, Klocke F, Childs THC (2007) Consolidation phenomena in laser and powder-bed based layered manufacturing. CIRP Ann ManufTechnol 56(2):730–759

[30] Christian Lindemann*, Ulrich Jahnke*, Thomas Reiher*, Rainer Koch, “Towards a sustainable and economic selection of part candidates for Additive Manufacturing”, 2014

[31] Jahnke, U.; Moi, M.; Koch, R., Lindemann, C.;: "Impact and Influence Factors of Additive Manufacturing on Product Lifecycle Costs"; 24th Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, Austin/Texas/USA, 12th-14th August

[32] H. Bikas& P. Stavropoulos & G. Chryssolouris, “Additive Manufacturing Methods and Modelling Approaches”, 2016

[33] ASTM F42, “Additive Manufacturing Standard”, 2019/Latest Version

[34] Solomon Dufera, “Additive Manufacturing Techniques”, 2019.

[35] Kathleen L. Sampson**,** Bhavana Deore, Abigail Go, Milind Ajith Nayak, “Multimaterial VAT Polymerization Additive Manufacturing”, 2021

[36] Wei Gao, Yunbo Zhang, Devarajan Ramanujan, Karthik Ramani , Yong Chen , Christ opher, B. Williams, Charlie C.L. Wang [e], Yung C. Shin, Song Zhang [a], Pablo D. Zavattieri, "The Status, Challenge and Future of Additive Manufacturing",2015

[37] Yue Wang, Yancheng Wang, "Printing Depth Modeling and VAT Polymerization", 2023

[38] Paul Gradl, Sandy E Greene, Christopher Protz, Brad Bullard, James Buzzell, Chance Garcia, Jessica Wood, Kenneth Cooper, James Hulka, Robin Osborne, Additive Manufacturing of liquid Rocket Engine Combustion Devices: A summary of process developments and Hot Fire Testing Results, 54th AIAA/ SAE/ ASEE Joint Propulsion Conference 2018

[39] Goran Flodberg, Henrik Petterson, Li Yang, Pore analysis and mechanical performance of selective laser sintered objects, Additive Manufacturing 24(2018) 307-315

[40] ShubhangTyagi,AmberYadav,Samadhan Deshmukh, "Review of 3D Printing Characterization using Material Jetting", 2021

[41] Miguel Angel Calle Gonzales, Pentti Kujala, "Additive Manufacturing of miniature marine structures", 2016

[42] ChanunSuwanpreecha, AnchaleeManonukul, "A Review on Material Extrusion Additive Manufacturing of metal", 2022

[43] Nesma T. Aboulkhair,Marco Simone,Luke Par, "3D printing of Aluminium alloys: Additive Manufacturing of Aluminium alloys using selective laser melting", 2018

[44] Sunpreet Singh, Seeram Ramakrishna, Rupinder Singh, Material Issues in Additive manufacturing: A Review, Journal of manufacturing processes 25(2017) 185-200

[45] Mustafa Yakout, M.A. Electability, Stephen C. Veldhuis,A study of thermal expansion coefficients and microstructure during selective laser melting of Invar 36 and stainless steel 316L, Additive Manufacturing 24(2018)405-418

[46] Chu Lun Alex Leung, Sebastian Marussi, Michael Towrie, Jesus del Val Garcia, Robert C Atwood, Andrew J Bodey, Julian R. Jones, Philip J Withers , Peter D.Lee, Laser- matter interactions in Additive Manufacturing of stainless steel SS316L and 13-93 bioactive glass revealed by in situ X-Ray imaging, Additive Manufacturing 24(2018) 647-657

[47] Ian Gibson, David W. Rosen & Brent Stucker, “Sheet Lamination Process”, PP223 – 252, 2010.

[48] AdritaDass&AtiehMoridi, “State of the Art in Directed Energy Deposition”, 2019

[49] Thompson, S.M.; Bian, L.; Shamsaei, N.; Yadollahi, A. An overview of Direct Laser Deposition for additive manufacturing; Part I: Transport phenomena, modeling and diagnostics. Addit. Manuf. 2015, 8, 36–62. [Google Scholar] [CrossRef]

[50] Caiazzo, F. Additive manufacturing by means of laser-aided directed metal deposition of titanium wire. Int. J. Adv. Manuf. Technol. 2018, 96, 2699–2707. [Google Scholar] [CrossRef][Green Version]

[51] Yuchu Qin, QunfenQiPaul J. ScottXiangqian Jiang, “Status, comparison and future of the representations of additive manufacturing data”, 2019.

[52] Tanisha Pereira [a], John V Kennedy [b], Johan Potgieter, “A comparison of traditional manufacturing vs additive manufacturing, the best method for the job”, 2019

[53] Lucideon. Additive Manufacturing Testing. Testing & Characterization 2017 [cited 2017 4/08]; Testing methods for quality assurance of additive manufactured parts]. Available from: https://www.lucideon.com/testing-characterization/additive-manufacturing-testing.

[54] Czichos, H., Handbook of technical diagnostics: fundamentals and application to structures and systems. 2013: Springer Science

[55] Zhang, C.; Liu, Y.; Lu, J.; Xu, L.; Lin, Y.; Chen, P.; Sheng, Q.; Chen, F. Additive manufacturing and mechanical properties of martensite/austenite functionally graded materials by laser engineered net shaping. *J. Mater. Res. Technol.* **2022**, *17*, 1570–1581.

[56] Bobbio, L.D.; Bocklund, B.; Reichardt, A.; Otis, R.; Borgonia, J.P.; Dillon, R.P.; Shapiro, A.A.; McEnerney, B.W.; Hosemann, P.; Liu, Z.; et al. Analysis of formation and growth of the σ phase in additively manufactured functionally graded materials. *J. Alloys Compd.* **2020**, *814*, 151729.

[57] Hu, Y.; Cong, W. A review on laser deposition-additive manufacturing of ceramics and ceramic reinforced metal matrix composites. *Ceram. Int.* **2018**, *44*, 20599–20612. [CrossRef]

[58] DebRoy, T.; Wei, H.L.; Zuback, J.S.; Mukherjee, T.; Elmer, J.W.; Milewski, J.O.; Beese, A.M.; Wilson-Heid, A.; De, A.; Zhang, W. Additive manufacturing of metallic components-process, structure and properties. *Prog. Mater. Sci.* **2018**, *92*, 112–224. [CrossRef]

[59] Herzog D, Seyd V, " Additive Manufacturing of Metals", 2016.