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Analysis of Various Metals in Comparison Using Additive Manufacturing and 3D Printing Technologies

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Abstract: Now a day's as additive manufacturing (or 3D printing) technology has advanced, several forming technologies now have unique traits and classification methods. The main forming methods for metal or non-metal (polymer) parts include SLA, SLS, SLM, WAAM, and EBM technologies, depending on the various deposition states of the forming materials. It is clear from a comparison of several metal additive manufacturing processes that none of the technologies discussed above have yet been able to satisfy the demands for high precision, superior mechanical characteristics, and affordability. Each procedure' benefits and drawbacks are examined, and the application fields are heavily introduced.
Keywords: Metal 3D Printing, Additive Manufacturing, SLA, SLS, SLM, and EBM.

I. INTRODUCTION

The discrete-stacking approach is the foundation of the emerging digital forming technology known as additive manufacturing (AM). It is referred to as "manufacturing technology with industrial revolution importance" and significantly reduces both the cost and length of the product development cycle. The growth of the industrial sector is extremely significant [1].

A variety of 3D printing (AM) techniques have characteristics and classification methods. The forming process of metal parts is mostly based on the various deposition states of the forming materials [2 - 4]: Stereolithography (SLA), Selective Laser Sintering, (SLS) Technique, Selective laser melting (SLM) Technique, Electron Beam Melting (EBM) Technique, Wire Arc Additive Manufacturing Technique, and Direct Metal Laser Sintering (DMLS).

II. STEREOLITHOGRAPHY (SLA)

SLA can produce parts with incredibly accurate measurements and delicate features, however parts are typically brittle and their mechanical characteristics may change over time, making them unsuitable for functional prototypes. This method is best suited for those tasks illustrated in figure 1 when mechanical attributes are not the primary design priority and rapid prototyping of design geometry and proof of concept of part interfaces or details are required.

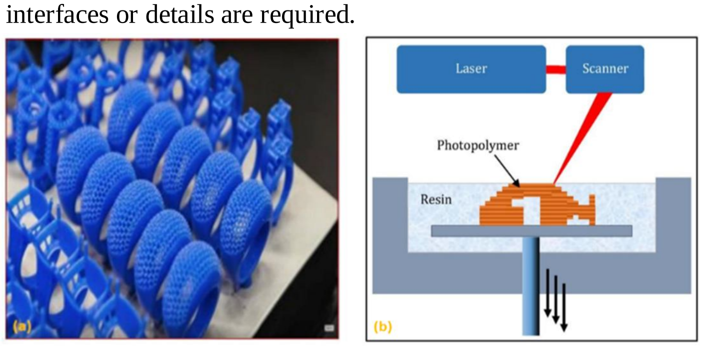

Figure 1: (a) Printed Parts, (b) Schematic illustration of SLA 3D printing technique. [5]

The main benefits and limitations of Stereolithography technique are:

1) High level of precision, excellent finish, and relatively fast process.
2) Relatively expensive, lengthily post processing time, restrained material use for photo-resins, and frequently requires support structures and post curing for components to be robust enough for structural application.

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III. SELECTIVE LASER SINTERING, (SLS) TECHNIQUE

Figure 2 is a schematic diagram of SLS Technique. The thermoplastic polymers that are utilized in SLS are available as granular materials. SLS may not be the best option for prototypes with fine details or tight tolerances because SLS parts are printed using many layers, which can lead to minor variances across parts. Using post-processing also makes it feasible to have a smooth surface finish. Rapid prototyping works best with SLS when part geometry or general fit and function are top design priorities. If post-processing is possible, SLS might also be useful for marketing or proof-of-concept prototypes.

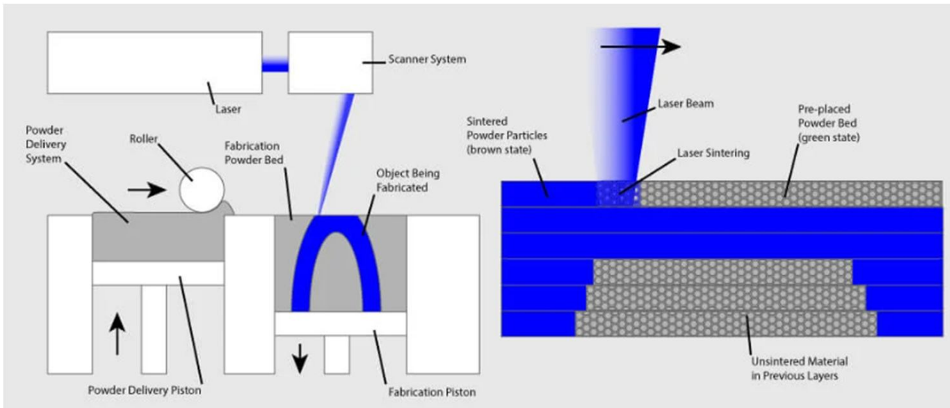


Figure 2: Schematic diagram of SLS forming technique. [6]

This method's average tolerance for forming precision is 0.05 to 2.5 mm. additionally, the unsintered powder can be employed directly as a support for the suspended layer during the forming process without the need for a support structure to be designed. As a result, the material utilisation rate is high, making this method the most efficient and least expensive of several popular AM processes.

The following are the primary drawbacks of the selective laser sintering (SLS) technique:

1) In order to produce layer-by-layer bonding, raw materials that have been powdered are heated and melted before being formed into the pieces. Therefore, the components' surface is strictly powdered, and as a result, the surface is rough or poor quality;
2) Poor mechanical properties are present. The prototype structure has poor mechanical characteristics because to its loose and porous construction and low component density.

IV. SELECTIVE LASER MELTING (SLM) TECHNIQUE

In metal additive manufacturing, sometimes known as 3D printing, includes selective laser melting, or SLM as shows in figure 3. The words direct metal laser sintering (DMLS) and SLM are frequently used interchangeably. However, there is a small distinction between the SLM melts pure metals, whereas DMLS fuses metal alloys, are the two technologies.

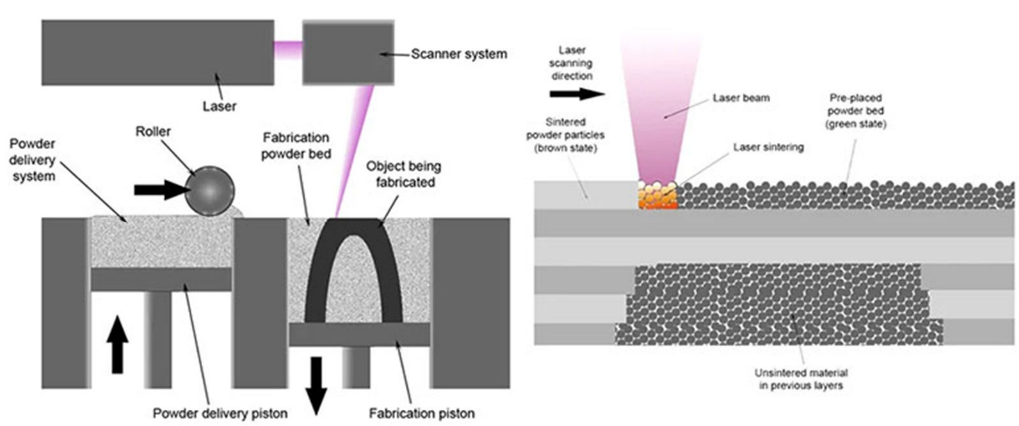


Figure 3: Schematic diagram of SLM 3D printing works. [7]

The metal materials used in SLM technique mainly include iron-based alloys, TiC4 alloys, 316L stainless steel powder, copper alloys, titanium alloys, tool steels, etc. [8]. A large number of these materials must be imported. The dimensional precision can be as accurate as 0.1 mm, and the surface forming accuracy can range from 30 to 60 µm. To create a structure that is entirely dense and has good mechanical properties (in Table 1), the metal powder can be completely melted.

Table 1: Mechanical properties of different materials in SLM 3D Printing.

Material	Tensile Strength (MPa)	Elongation (%)	Hardness (HB)	Surface finish (µm)	Accuracy (±mm)	Density (%)
Copper	200-250	30-40	50-51	Ra0.3-0.4	<0.1	100
Stainless Steel	480-520	10-15	220-250	Ra30-60	<0.1	100
Tool Steel	780 840	2-3	50-54	Ra30-60	<0.1	100
Ti-6Al-4V	1200 - 1400	1-2	380-420	Ra30-60	<0.1	100

Due to SLM products' superior strength compared to the technology used in most other metal 3D printed items are highly sought after in high-end applications. The pros and cons of SLM printing are given below.

1) SLM produces very accurate and detailed, completely metal, high-performance products.
2) High-strength and speciality metals are included in the broad spectrum of materials used in SLM.
3) SLM can produce extremely complex geometries and reduce part counts by printing entire assemblies.
4) Only specified materials with suitable flow properties and single-component metals are acceptable in SLM.
5) SLM requires a source of inert gas and significant support structures for its pieces.
6) Out of the printer, SLM parts have a rough surface texture, necessitating extensive post-processing.
7) SLM can only be used for small-batch manufacturing runs because it is very expensive and has a size constraint on parts.

V. ELECTRON BEAM MELTING (EBM) TECHNIQUE

EBM is best suited for quick prototyping where material qualities are a design priority, just like SLM and DMLS, and it can be economical when component finish is not an issue. The key distinction is that EBM has fewer applications for materials (such as titanium, chromium-cobalt alloys, tool steel, nickel alloy, molybdenum alloy and other conductive metal), but may be the best choice for niche businesses that need these materials, such the aviation or medical sectors as shows in figure 4.

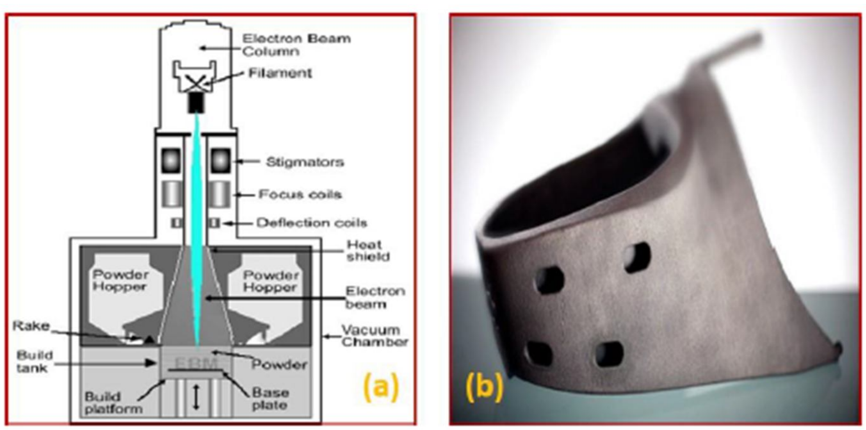


Figure 4: (a) Schematic illustration of AM electron beam melting technique, and (b) fabricated part of aviation. [9]

However, the electron beam deposition requires a vacuum environment with a high degree of vacuum, and the cost of the equipment is expensive; and the electron beam will be accompanied by the emission of gamma rays during the deposition process. If the device design is unreasonable, it will cause radiation leakage and environmental pollution. In addition, the electron beam can only deposit conductive materials, not plastics, ceramics and other non-conductive materials. [10]

In EBM, like any other additive manufacturing technology, has benefits that make it suited for specific applications as well as limitations that prevent widespread adoption.

1) Highly suitable for metal parts, faster than laser sintering, No support structures needed, and appropriate for low-volume requirements.
2) Lower accuracy than laser sintering or melting, limited build volume, and an only conductive metals.

VI. WIRE ARC ADDITIVE MANUFACTURING (WAAM) TECHNIQUE

The wire arc additive manufacturing (WAAM) technique (shows as figure 5) is classified into three types based on the heat source and melting method [11–13]:

1) Gas tungsten arc welding (GTAW);
2) Plasma arc welding;
3) Gas metal arc welding (GMAW) / (PAW).

A consumable wire filament and the work piece create an electric arc during the GMAW process. Normally, the wire is parallel to the substrate. The melt track is created via PAW and GTAW employing a non-consumable tungsten filament. In comparison to GTAW, plasma arc typically results in finer tracks [14], less weld distortion, and greater building rates [15].

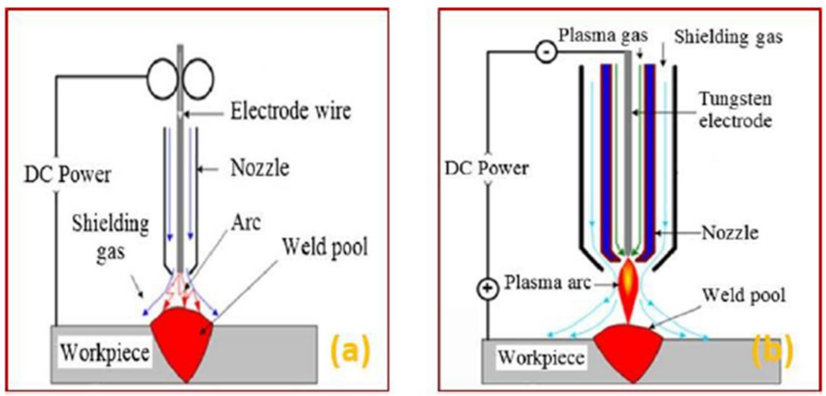


Figure 5: Schematic diagram of MIG Welding, and (b) Plasma Arc Welding Process [16].

The Benefits and disadvantages of WAAM technique are:

a) Possibility to weld super alloys, making large components possible, and fast AM process.
b) Residual stresses and distortions, not as accurate as EBM and Direct laser deposition, poor surface finish, and some materials require shielding.

VII. DIRECT METAL LASER SINTERING (DMLS) TECHNIQUE

Direct metal laser sintering ((DMLS), shown as figure 6), A form of metal additive manufacturing, or 3D printing, is selective laser sintering (SLS), often known as. It is utilised for both quick prototyping and large-scale manufacturing of metal components. [17].

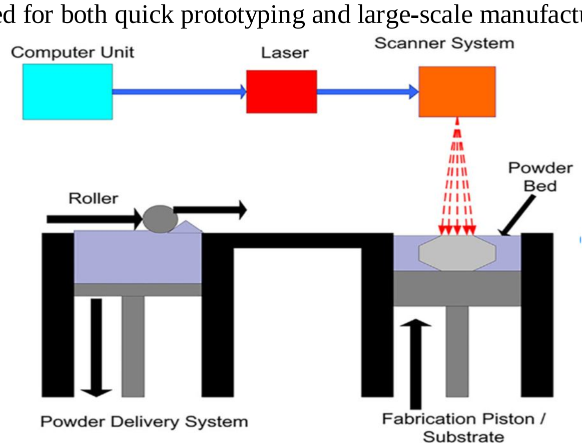


Figure 6: Schematic illustration diagram of direct metal laser sintering method. [18]

The procedure is very similar to selective laser melting (SLM), also referred to as direct metal laser melting (DMLM), however the powder is only molecularly sintered together, and not melted. This results in bits that are less permeable than melting. This has the advantage of making alloys with components with different melting points easy to print from. Metal and plastic materials can even be blended. Alumide, which is a combination of nylon powder and aluminium powder, is a nice illustration.
The fusion of the metal powder at its temperature in these two processes, sintering and melting, is another distinction between them. The SLM heats the metal powder until it completely turns into a liquid and DMLS does not melt the metal powder, hence less energy is used. During sintering, particles are sufficiently heated for their surfaces to fuse together.
Metal powdered to a fine consistency is the working material for this 3D printing method. The normal size range for the metal particles is 20 to 40 µm. The particle size and shape have an impact on the detail resolution of the finished item. Smaller metal particle sizes and less variance enable best resolution.

The Benefits and limitations of DMLS technique are:
1) Pure metals or metal alloys without modifying the material's qualities;
2) Wide range of metal and metal alloy powders;
3) The DMLS method results in robust, useful metal items;
4) The cost of the equipment and the materials, as well as the length of the procedure;
5) Finished DMLS components have pores compared to molten metal part and small build volumes.

Table 2 is a comparison of additive manufacturing techniques for metal and polymer 3D printing. It can be seen that no single technology can meet the requirements of high accuracy, excellent mechanical properties and performance. The advantages and disadvantages of each process are obvious, and the application fields are significantly different.

Table 2: Comparison of additive manufacturing techniques.

Density	100%	> 90%	> 90%	> 90%	> 90%
Printer Model	self-made Welding Setup (MIG/TIG)	Sinteratac S1	Concept Laser SLM	RITON D100	EBM S12
material	wire	powder	powder	powder	Powder / wire
Heat source / power	Induction / 25 kW	Laser / < 100 W	laser /200W~1 kW	laser / > 4.5 kW	Electron beam /3.5 kW
Maximum shaped piece size /mm	Not restricted	800×800	500×500	1300x900	400×400
Application area	Parts repair, nested components, etc.	Aerospace mold parts, etc.	Mold, medical treatment, electricity	Mold, medical treatment, electricity	Parts repair, biomedical

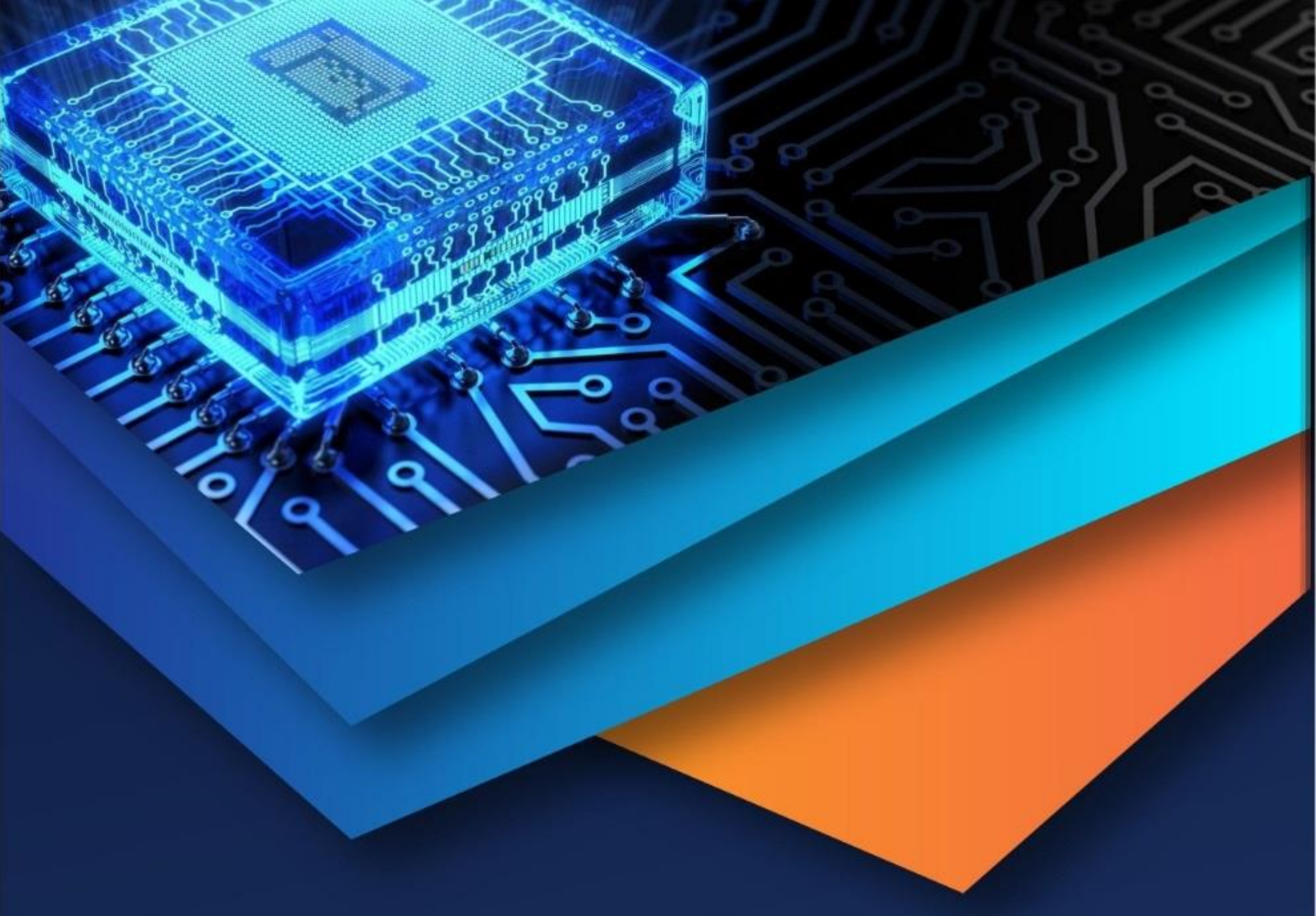
VIII. CONCLUSION

These characteristics of metal additive manufacturing technique are in line with the needs of the quick, individualised, and adaptable growth of modern manufacturing. As a result, a focus area for AM research has emerged the utilisation of direct metal 3D printing. There has been extensive use in the biomedical, aviation, automobile and other manufacturing sectors, and these industries have excellent application possibilities [19–20].

REFERENCES

[1] Bennon, W.D., and Incropera, F.P., "Developing Laminar Mixed Convection with Solidification in a Vertical Channel", ASME Journal of Heat Transfer, Vol. 110, pp. 410-415, (1988).
[2] L.J. Za rza l e j o, K.S. Schma l t z, C .H. Amo n, M o l t e n droplet solidification and substrate remelting in micro casting PartI: Numerical modeling and experimental verification, Heat Mass Transfer 34 (1999) 477–485.
[3] J.P. Kruth, Material increases manufacturing by rapid prototyping techniques, Ann. CIRP 40 (2) (1991) 603–614.
[4] M. Orme, A novel technique of rapid solidification net form materials synthesis, J. Mater. Eng. Perform. 2 (3) (1993) 399–405.
[5] J. W.; Idacavage, M. J. 3D Printing with Polymers: Challenges Among Expanding Options and Opportunities. Dent. Mater. J. 2016, 32, 54-64.

[6] https://3dprinting.com/what-is-3d-printing/#3D-Printing-Technologies
[7] https://www.pcbway.com/rapid-prototyping/3D-Printing/3D-Printing-SLM.html
[8] M. Orme, C. Huang, J. Courte, Deposition strategies for control of microstructures micro porosity and surface roughness in droplet- based solid freeform fabrication of structural materials, in: EF Matthys, WG Truckner (Eds.), Melt Spinning, Strip Casting and Slab Casting, The Minerals, Metals and Materials Society, Warrendale, PA, 1996, pp. 125–143.
[9] Sidambe, Alfred T. (2014), "Biocompatibility of Advanced Manufactured Titanium Implants-A Review" Materials; Basel Vol. 7, Iss. 12, 8168-8188.
[10] Neagu. M. Study of remelting process during the droplet-based solid freeform fabrication [J]. The annals dungaree de jobs University of Galati, fascicle v: technologies in mechanical engineering, 2004, 5: 35-39.
[11] https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditive manufacturing/material jetting.
[12] https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditive manufacturing/binder jetting.
[13] http://teknologiworkshop2.blogspot.com/p/rapid-prototyping.html.
[14] Kumar, S. A., & Prasad, R. V. S., (2021), "Basic principles of additive manufacturing: different additive manufacturing technologies", In Additive Manufacturing (pp. 17-35).
[15] Stecker, S. et al, "Advanced Electron Beam Free Form Fabrication Methods & Technology", Salo Sciaky Incorporated, Chicago, Illinois, USA.
[16] Donghong Ding, et al, "Li Wire-feed additive manufacturing of metal components".
[17] https://all3dp.com/2/direct-metal-laser-sintering-dmls-simply-explained/
[18] Panda, B. K. and Sahoo S, "Thermo-mechanical modeling and validation of stress field during laser powder bed fusion of AlSi10Mg built part", Results in Physics 12 (2019) 1372–1381.
[19] George Strotos, Manolis Gavaises, Andreas. Numerical investigation on the evaporation of droplets depositing on heated surfaces at low Weber numbers. International Journal of Heat and Mass Transfer. 45 (2007): 213-216.
[20] Fukai, J., Shiliba, Y., Yanmaoto et al. Wetting effects on the spreading of a liquid droplet colliding with a surface: experiment and modeling. Phys. Fluids 1995, 7 (2): 236-247.



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