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A REVIEW ON METAL BASED ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing (AM) is a process of creating a three-dimensional solid object from a digital file by adding materials layer by layer. This is the opposite of subtractive manufacturing additive manufacturing enables the creation of complex shapes and structures that cannot be produced through traditional manufacturing methods. whereas Metal additive manufacturing (AM) is also a process of creating three-dimensional metal parts layer by layer, using various technologies to fuse or deposit metal powders or wires. This process allows for the creation of complex geometries, structures, and shapes that cannot be produced through traditional metal manufacturing methods. This review focusses on layer-by-layer bonding in metal additive fabrication. It addresses metals and various alloys. The technologies included in the MAM are direct energy deposition, powder bed fusion, binder jetting, and material extrusion. Along with the ability to lower costs and energy usage, it makes distributed manufacturing and parts-on-demand production possible. the impact of significant process variables on the final part's mechanical characteristics and microstructure. Layer by layer bonding is fast and effective, providing outstanding mechanical qualities together with great precision. AI, SI, MG, and other alloys are to be used as the materials. In this review we studied about the working principle of different types of MAM process and also can generates the complex shapes and structures…etc. the application is to be in aerospace industries, medical implants, automobile industries, unique desired shapes.

Keywords: metal additive manufacturing, medical implants, aerospace, industry, layer, machine learning.

I. Introduction

Metal-based additive manufacturing (AM), also known as metal 3D printing, is a process of creating three-dimensional solid objects from digital files by layering metal materials. This technology has revolutionized the manufacturing industry by enabling the rapid production of complex geometries, reducing material waste, and increasing design flexibility. The text describes various methods used in Metal Additive Manufacturing (MAM), including: Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), Directed Energy Deposition (DED), Laser Beam Melting (LBM), Powder Bed Fusion (PBF), Laminated Object Manufacturing (LOM), Wire and Arc Additive Manufacturing (WAAM), Hybrid Manufacturing. The text also lists common materials used in MAM, such as aluminum alloys, titanium alloys, stainless steel, and nickel-based alloys. The applications of MAM include: Aerospace, Automotive, Medical, Industrial equipment, Tooling, Defense. This MAM enables the production of complex geometries, customized parts, and reduced material waste, making it an attractive option for various industries.

II. Literature

A Review On metal based additive manufacturing, It’s Process and applications in various sectors, advantages, disadvantages, future scope we studied some of the journal papers and mentioned them, below:

Mahrukh Sadaf et.al., [1] Material Extrusion (MEX) is a widely used Additive Manufacturing (AM) method for producing thermoplastic polymers and composites. The process involves 3D printing with polymer feedstock highly filled with metal particles, followed by debinding and sintering to produce a fully densified solid component. MEX offers several advantages, including low initial investment, short processing time, minimal material wastage, user-friendly operation, and seamless integration with diverse computer-aided design (CAD) software. The review discusses the interconnected stages of MEX-based processing, including powder selection, binder development, compounding, 3D printing, and post-treatment. The article highlights the potential of MEX to produce complex components with high accuracy and precision, making it a promising technology for various industrial applications, including aerospace, medical, and consumer goods. The working principle of MEX technology involves introducing a filament into a printing machine, melting it, and extruding it through an orifice or nozzle to create the desired shape. The review also discusses the choice of metal for MEX, with various metals investigated for utilization, including stainless steel, copper, and bronze.

D.R. Gunasegaram et.al., [2] The article discusses the limitations of traditional closed-loop control (CLC) in metal additive manufacturing (AM) and proposes a machine learning (ML)-assisted framework for defect and anomaly control. AM is a complex and dynamic process, and traditional CLC methods are insufficient to ensure defect-free parts. ML-based strategies offer robustness, flexibility, and scalability, enabling real-time detection, diagnosis, and correction of flaws. The article identifies a knowledge gap in the implementation of adaptive process control strategies in AM and proposes a framework for ML-assisted CLC. The framework consists of three components: direction setting, diagnostics, and prognostics. Direction setting involves defining performance requirements via set point establishment using ML-based optimization algorithms. The article discusses the potential of ML algorithms to direct, monitor, and control the AM process, and highlights the need for a regulatory framework and technological advancements for commercial adoption.

T. Herzog et.al., [3] The article discusses the challenges of defect detection in laser-based metal additive manufacturing (MAM) and proposes a machine learning (ML) framework for process condition monitoring. MAM is prone to defects that can compromise product quality, and the industry needs effective defect detection methods. The authors propose using ML approaches and in-situ monitoring technologies to monitor the AM process and detect defects in real-time. They discuss the potential of ML algorithms to analyze data from sensors and detect defects, and highlight the importance of quality control in AM processes. The article concludes that addressing defect detection challenges is crucial for further adoption of AM by high-value industries. The proposed ML-based framework has the potential to improve the quality and consistency of MAM parts, reduce post-processing needs, and enable wider adoption of AM. Overall, the article emphasizes the importance of defect detection and process monitoring in MAM and proposes a promising solution using ML.

Pouya Moghimian et.al., [4] The article examines the reusability and recyclability of titanium, nickel, and aluminum alloys in metal additive manufacturing (AM). It discusses the production methods of AM metal powders and the factors affecting their characteristics. The focus is on three common alloys: Ti-6Al-4V, nickel alloy 718, and Al-Si10-Mg. The authors highlight the importance of powder reusability in reducing production costs, but note that it's influenced by factors like chemical composition, contamination, and mechanical properties. They conclude that developing standards for powder feedstock characteristics is a current challenge in AM. Ensuring consistent mechanical and physical properties in printed parts is crucial, but variations in powder characteristics and manufacturing methods make this difficult. The article emphasizes the need for further research and standardization to ensure consistent properties in printed parts, particularly in high-value industries like aerospace and healthcare.

Ana Vafadar et.al., [5] The article provides a comprehensive review of metal additive manufacturing (AM) technologies, applications, and limitations. It discusses common metal AM processes, advantages over conventional manufacturing, and leading industries. However, the adoption of metal AM is slow due to challenges such as: Printing quality, post-processing requirements, Maintenance needs, Material limitations, Geometry accuracy, Part size limitations, Lack of standardization, High costs. The authors conclude that metal AM has the potential to revolutionize industries, but addressing these challenges is crucial. The article provides a robust understanding of metal AM processes and considerations, helping industries select suitable technologies. It serves as a valuable resource for industries considering metal AM adoption and researchers working to address associated challenges. Overall, the article offers a comprehensive overview of metal AM, highlighting its advantages, challenges, and limitations, and emphasizes the need for further research and standardization to overcome existing hurdles and unlock the full potential of metal AM.

Vladimir C.M. Sobota et.al., [6] The article investigates the key factors influencing the selection of Additive Manufacturing (AM) technology for metal part production. Despite AM's capabilities and growing interest, its practical applications are limited. The study identifies and prioritizes factors affecting AM technology selection, focusing on metal AM, through a literature review, expert interviews, and the Best-Worst Method. Four categories of factors are revealed: technology-related, demand-related, environment-related, and supply-related. The top four factors are: Market demand, Relative technological performance, Imitability, Scalability, integrability, and stakeholder identification. The study provides a holistic framework for selecting suitable AM technology, enhancing Western manufacturing industries' competitiveness. The article provides valuable insights into AM technology selection, highlighting the importance of considering multiple factors beyond technical capabilities.

Mostafa Yakout et.al., [7] The article provides a comprehensive review of metal additive manufacturing (AM) technologies, focusing on the effect of process parameters on the microstructure and mechanical properties of the resulting part. The authors discuss various metal AM processes, including selective laser sintering (SLS) and selective laser melting (SLM), and their applications. The article highlights the benefits of AM, including the ability to produce complex geometries and customized parts with minimal material waste. However, it also notes that AM parts can have defects such as voids, lack of adhesion between layers, and substandard mechanical properties. The authors discuss the working principle of SLM, which involves full melting of powders to produce fully dense objects with mechanical properties comparable to bulk materials. They also note that not all metals can be processed using SLM due to differences in laser absorption, surface tension, and viscosity.

Yi Zhang, et.al., [8] The article reviews the latest developments in additive manufacturing (AM) of metallic materials, focusing on four common methods: powder bed fusion, direct energy deposition, binder jetting, and sheet lamination. The authors discuss the process principles, microstructures, and mechanical properties of AM-fabricated parts. The authors also discuss the processing steps and equipment used in each method, including selective laser melting (SLM) and electron beam melting (EBM). The article concludes by suggesting future research directions, including: Theoretical studies using AM process modeling to advance understanding of heat and mass transfer, melting pool prediction, residual stress and distortion evolution, atomistic diffusion, densification, phase change, Investigation of new AM techniques and materials, Improvement of AM process efficiency and productivity, Development of hybrid AM processes. The article provides a comprehensive overview of the latest developments in AM of metallic materials, highlighting the benefits and challenges of this rapidly evolving field.

John J et.al., [9] The article reviews the mechanical properties of additively manufactured metallic materials, focusing on powder bed fusion (PBF) and directed energy deposition (DED) techniques. It summarizes published data on various alloys, including Ti-6Al-4V, TiAl, stainless steel, and Al-Si-10Mg. The authors highlight the effects of processing conditions on microstructures and mechanical properties, noting that nonequilibrium microstructures and defects can occur. Postprocessing techniques like heat treatment and HIP can improve microstructural features and reduce defects. The article provides summary tables and figures for each alloy class, documenting the effects of specimen orientation on tensile properties. Limitations of current research include the lack of efficient tools, in situ monitoring systems, material standards, and recyclability issues. The article provides a comprehensive review of the mechanical properties of additively manufactured metallic materials, highlighting the current state of research and the need for further advancements.

William E. Frazier et.al., [10] The article reviews the state-of-the-art of metal additive manufacturing (AM), a rapidly emerging technology with the potential to revolutionize global parts manufacturing and logistics. AM enables distributed manufacturing, production of parts-on-demand, and offers potential cost, energy consumption, and carbon footprint reductions. The article provides a contextual overview of metallic AM, including its definition, history, and working principle of powder bed systems. It highlights the importance of developing integrated in-process sensing, monitoring, and controls, and understanding machine-to-machine variability. Despite complexities, the static mechanical properties of AM metallic materials are comparable to conventionally fabricated components. The article emphasizes the need for further research to address challenges and limitations, including integrated in-process sensing and understanding machine-to-machine variability. It serves as a valuable resource for researchers, manufacturers, and industry professionals interested in this rapidly emerging technology.

laura E.T.mathias et.al., [11] The article discusses the crucial role of metal powders in laser-based additive manufacturing (AM) processes, specifically laser powder bed fusion (L-PBF) and direct laser deposition (DLD). Powder characteristics, such as particle size, morphology, and flowability, significantly impact processing and printing results. The authors explain how powder production processes, like atomization, affect powder properties, which in turn influence processing parameters and built part characteristics. The article also addresses challenges with certain metal powders, like aluminum alloys, and suggests modifying the powder's surface to improve processability. The authors emphasize the need to understand relationships between powder characteristics, processing parameters, and built part properties to optimize AM processes and produce high-quality components.

Tugrun Ozel et.al., [12] The article reviews wire-fed directed energy deposition (DED) based metal additive manufacturing, a cost-effective process for fabricating large parts. However, achieving reliable mechanical properties and homogeneity in microstructure and grain size remains challenging. The article discusses advancements in metal additive manufacturing, including improvements in microstructure and mechanical properties. It focuses on two main classes of AM used for metallic aerospace applications: Directed Energy Deposition (DED) and Powder Bed Fusion (PBF). The article explains the processes of PBF and DED, and presents examples of wire-fed DED systems. It showcases the use of wire-fed DED in producing large, complex components, such as aircraft structural components. The conclusion highlights the growing importance of additive manufacturing, the significance of microstructure and grain size on mechanical properties, and the impact of alloying particles, process control, and post-processing on final microstructure and mechanical properties.

Nacol Dessalegn Dejene et.al., [13] The article reviews the current status and challenges of powder bed fusion (PBF)-based metal additive manufacturing, focusing on selective laser melting (SLM). PBF is a widely used technology that can fabricate complex geometries using various materials, but part quality and reliability are crucial aspects that need improvement. The article discusses the emergence of additive manufacturing as a revolutionary technology that has transformed the manufacturing paradigm. Metal-based additive manufacturing technologies have tremendous application potential, and PBF is widely employed in various industries. The article explains the working principle of PBF and its history, from selective laser sintering (SLS) to SLM. The article concludes by highlighting SLM's advantages (high product customization, minimal) and challenges. Addressing these challenges is crucial for SLM's successful adoption in various industries. The article emphasizes SLM's potential in additive manufacturing and its ability to manufacture complex materials, making it a promising candidate for mission-oriented applications like aerospace, defense, and healthcare.

Yun Zhai et.al., [14] The article reviews the progress of metal-based additive manufacturing (3D printing) in creating medical implants. This technology offers advantages over traditional methods, including customized design, reduced lead time, and complex geometries for patient-specific implants. The article discusses various metal 3D printing technologies (SLS, SLM, EBM) and materials (titanium alloy, medical stainless steel). It highlights the importance of metal implants in the biomedical field and the growth of the metal implant market in China. The article explains the working principle of SLS and its advantages, including a wide range of materials, elimination of support structures, and accelerated manufacturing speed. It showcases applications of metal 3D printing in medical implants. The conclusion highlights challenges and issues faced by metal 3D printing in implants, including biocompatibility, material selection, precision, surface quality, printing speed, and material cost. The article emphasizes the potential of metal-based additive manufacturing in creating customized medical implants and the need to address challenges to ensure successful adoption in the biomedical field.

Mahathir Mohammad Bappy et.al., [15] The article discusses the risks of sharing process data in Manufacturing-as-a-Service (MaaS) for additive manufacturing (AM), specifically in metal-based AM anomaly detection. Sharing process data may reveal sensitive product design information, such as printing orientation. To evaluate this risk, the article assesses various thermal history-based feature extraction methods for their ability to retain design information and preserve data usability for anomaly detection. The article highlights the challenge of balancing data sharing for collaborative AM process-defect modeling with the need to protect sensitive product design information. A framework is proposed to evaluate the design information disclosure and utility of feature extraction methods for Anomaly Detection (AD) in Additive Manufacturing (AM) based on thermal images. Six feature extraction methods are compared using three classification models, showing that the process feature extraction method plays a crucial role in both utility and design information disclosure risks.

Haoyang luo et.al., [16] The article reviews the current state of research on stress determination and control in metal-based additive manufacturing (MAM). Residual stress is a significant issue in MAM, leading to distortion, delamination, and cracking in formed parts. The article discusses the importance of residual stress, its classification, and effects on product quality. Various measurement techniques and stress control approaches are reviewed, including numerical models, thermal mechanical models, and finite element simulations. In-situ monitoring and prediction of residual stress from processing parameters are crucial to improve product reliability and repeatability. Further research is needed to develop more efficient methods for measuring and controlling residual stress in MAM. The article provides a comprehensive review of the current state of research in this field, highlighting challenges and opportunities for improvement.

Yanzhou fu et.al., [17] The article reviews recent research on machine learning (ML) algorithms for defect detection in metal laser-based additive manufacturing (LBAM) processes. LBAM is a rapidly growing technology with advantages in design freedom and complex geometries, but faces challenges in repeatability, durability, and reliability. The article discusses the working principle of LBAM processes, including Directed Energy Deposition (DED) and Laser Powder Bed Fusion (LPBF), and highlights the complexity of these processes. The article focuses on the application of ML algorithms for defect detection in LBAM, providing a comprehensive reference for selecting suitable algorithms based on various factors. The conclusion emphasizes the potential of ML algorithms for improving fault detection capabilities in LBAM processes and the need for further research to develop more accurate and efficient algorithms.

Shenghanguo et.al., [18] The article discusses the application of machine learning (ML) in metal additive manufacturing (AM) and its limitations. It highlights the need for transparency and consistency with physical principles in ML models, leading to the emergence of physics-informed machine learning (PIML). PIML combines data-driven methods with physical domain knowledge, such as thermomechanical laws and constraints. The article provides an overview of metal AM processes, including powder bed fusion (PBF) and directed energy deposition (DED). It discusses the advantages of ML methods, including computational efficiency and adaptability to process variability, but also notes their limitations, such as lack of physical interpretability and susceptibility to data pollution. PIML offers advantages, including low training time, real-time responsiveness, data-driven decision logic, and uncertainty quantification. Its primary benefit is innate physical consistency, compared to purely data-driven methods.

Xin lin et.al., [19] The article reviews current research on metal-based additive manufacturing (MAM) process monitoring and control. MAM technologies have advanced significantly, with various processes like selective laser melting (SLM) and electron beam melting (EBM). The MAM process involves layer-by-layer fusion of material using high-energy sources, producing various signals like radiation, acoustic, and electronic signals. These signals can be used to monitor the build process and detect defects, improving manufacturing stability and final product quality. The article discusses various measurement techniques, including infrared radiation, visible lights, and acoustic transducers. The article concludes by summarizing the state-of-the-art MAM process monitoring methods, discussing their advantages and disadvantages, and highlighting the importance of process measurement, signal acquisition, feature extraction, classification, and control approaches in improving MAM process stability and final product quality.

Davide cannizzaro et.al., [20] The article presents a framework for in-situ defect detection in metal Additive Manufacturing (AM) using computer vision and machine learning. The authors highlight the importance of monitoring systems in AM to detect defects layer-by-layer, improving product quality and reducing post-process analysis. They propose a real-time monitoring system that uses computer vision, machine learning, and data augmentation to detect defects and improve efficiency and reliability. The system uses a low-cost camera setup to acquire images of the build plate, which are then processed using machine learning algorithms to detect defects. The authors also propose a distributed software infrastructure for AM, allowing for data collection, integration, and storage at all stages of the AM pipeline. The system can be easily integrated into existing AM machines and has the potential to enhance efficiency and reliability.

Kunpeng Zhu et.al., [21] The article reviews metal-based additive manufacturing (MAM) processes, applications, and common defects. MAM produces high-performance metal components with complex structures, used in aerospace, biomedical, and automotive industries. However, defects limit its application in industries requiring high quality and reliability. The authors propose a machine learning (ML) framework for process condition monitoring to improve final product quality control. The article classifies process monitoring methods into physical-based and data-driven methods. Four areas for further research are identified: Feature extraction and defect mechanism mapping, Defect detection under multiple modes, Deep learning for defect recognition and adaptation capability, Real-time monitoring and control. The authors aim to improve MAM process consistency and final product quality control by exploring the building mechanism, understanding defect formation and evolution, and developing advanced monitoring systems.

Kyota egashira et.al., [22] The article investigates pore formation in metal-based additive manufacturing (AM) using powder bed fusion (PBF). PBF can result in pore formation, degrading mechanical strength. The study focuses on the influence of substrate temperature on pore formation and finds that controlling substrate temperature reduces large pore formation, improving mechanical strength. Experiments using AISI 1049 carbon steel show that pore number decreases with increasing substrate temperature, with a greater decrease at the upper position due to repeated melting and solidification under laser beam irradiation. The study concludes that optimizing substrate temperature and process parameters produces high-density parts with minimal pores, enhancing product quality and reliability. The article provides insights into the pore formation mechanism in PBF and highlights the importance of controlling substrate temperature to improve mechanical strength.

Chen chen et.al., [23] The article presents a new additive manufacturing (AM) technology that uses metal foils as feedstock to produce 3D metal parts. This technology combines laser raster-scan welding and foil-cutting to fabricate high-quality 3D metal parts with improved mechanical properties. The authors describe the system setup and procedure, including laser foil-welding and foil laser cutting. They fabricate 3D AISI 1010 steel parts and examine their mechanical properties, finding significant improvements in microhardness and tensile strength compared to the original foil. The laser welding process creates strong bonding between the foil and substrate, leading to enhanced mechanical properties. The study contributes to the development of new AM technologies that produce high-quality 3D metal parts with improved mechanical properties, reducing material waste and improving efficiency.

Wentao fu siemens, et.al., [24] The article discusses the challenges and solutions for metal-based additive manufacturing (AM) in the gas turbine industry. Siemens Power & Gas has established cross-divisional competence centers for AM to address these challenges. The benefits of AM in the gas turbine industry include radical design changes, shorter design-to-product process chain, rapid prototyping and manufacturing, and potential for reduced product cost and lead-time. However, material characterization and process development are highly specific to a particular AM system, leading to significant time and effort when changing systems or introducing new materials. The article proposes two frameworks to address these challenges: a material characterization and process development framework and a design for additive manufacturing (DFAM) framework. The article concludes that the two frameworks have significantly expedited the industrialization of metal-based AM technologies, and will promote metal-based AM technologies in a broader gas turbine industry.

John a.slotwinski et.al., [25] The article discusses the benefits and challenges of Additive Manufacturing (AM) with a focus on metal powders. While AM has the potential to revolutionize manufacturing, challenges include metrology issues with measuring and characterizing metal powders. Characterizing powders is crucial, including size, shape, chemistry, and morphology. Standardized methods for qualifying and certifying AM parts and materials are needed, as well as AM-specific methods for interlaboratory studies. The microstructure of the powder is critical, and advanced powder geometry methods may be necessary. Research and development efforts are addressing technical challenges, including standardization efforts like ASTM F3049, the first AM powder-specific standard. Ongoing research and development, as well as standardization efforts, can address challenges associated with metal powders, leading to greater AM proliferation.

Leroy Gardner et.al., [26] The article reviews the current state of metal additive manufacturing (AM) in structural engineering, focusing on the Directed Energy Deposition-arc (DED-arc) or wire arc AM (WAAM) technique. The authors discuss recent developments, research advances, and practical applications, highlighting WAAM's potential benefits in construction, including improved economy, sustainability, safety, and productivity. The article covers material response, structural behavior, connections, and optimization, noting WAAM's ability to produce complex geometries optimized for specific structural applications. Further research is needed to address uncertainties and develop a design framework and safety factors. The article concludes that metal AM, particularly WAAM, is a viable method for construction, offering suitable speed, scale, and accuracy. The article provides a comprehensive overview of metal AM in structural engineering, highlighting its potential benefits and challenges, and emphasizing the need for further research and development.

Paul Gradl et.al., [27] The article discusses the challenges of selecting the most suitable metal additive manufacturing (AM) process for aerospace applications. With various AM processes available, each with its advantages and challenges, determining the best process for a specific application can be complex. The authors highlight the importance of considering several attributes, including geometric considerations, metallurgical characteristics, cost basis, post-processing, and supply chain maturity. Various AM processes are discussed, including powder bed fusion, directed energy deposition, and solid-state processes, each with its unique advantages and disadvantages. The article concludes that metal AM is becoming increasingly popular in aerospace due to its technical capabilities, but careful consideration of various factors is required to ensure the optimal process is chosen for a specific application. A systematic approach to AM process selection can help aerospace manufacturers leverage the benefits of metal AM while addressing its challenges.

Alberta Aversa et.al., [28] The article reviews the progress of metal additive manufacturing (AM) technologies through a patent investigation. The authors analyzed patent trends and identified key players, including companies, AM machine producers, end users, universities, and research centers. Steel alloys have the largest number of patents, followed by Ti and Al alloys, while Ni alloys have the lowest number. The patent landscape reflects the industry's focus on specific alloy classes for various applications. The article concludes that the continuous growth in metal AM patent numbers indicates increasing interest and investment in the field, with companies, universities, and research centers being the main assignees. The study provides insights into the development and application of metal AM technologies, highlighting the importance of patent analysis in understanding innovation trends.

Guang hao Gong et.al., [29] The article reviews the current state of laser additive manufacturing (LAM) for metals, highlighting its benefits, applications, and challenges. LAM offers rapid prototyping, customization, and high material utilization, and can be divided into three categories: LAM, wire and arc additive manufacturing (WAAM), and electron beam additive manufacturing (EBAM). The article focuses on LAM, which has two main methods: synchronous powder feeding and powder bed forming method. The development status of various metallic materials is presented, and challenges such as low manufacturing efficiency and accuracy are discussed. Optimization of processing parameters and numerical simulation can improve performance, and adding additives and heat treatments can enhance part quality. Overall, LAM is a promising technology with numerous benefits, but requires further optimization and development to overcome its challenges and limitations.

Shaun Cooke et.al., [30] The article provides a comprehensive review of metal additive manufacturing (AM), covering its current processing methods, physics, and challenges. The authors discuss common defects like porosity and irregular cracks, and review commercially available metals and alloys. They also cover process optimization techniques, computational modeling, and post-processing methods to improve surface roughness, mechanical properties, and dimensional precision. The article highlights the importance of understanding metal AM physics, including melt-pool characterization, processing defects, and printable alloys. It compares three common metal printing methods: powder bed fusion (PBF), direct energy deposition (DED), and binder jetting, and discusses laser and electron beam heat sources. Overall, the article provides a thorough overview of metal AM, its challenges, and opportunities for improvement.

Irene Buj-Corral et.al., [31] The article reviews the development of additive manufacturing (AM) technologies for metals in the medical implant sector. The authors discuss the benefits of AM, including producing custom implants with porous structures that facilitate osseointegration, improving fixation and reducing complications. They summarize the properties of metals used in medical implants, focusing on ferrous and non-ferrous alloys like stainless steel, CoCr alloys, titanium, and tantalum. The ideal properties of alloys for implants include biocompatibility, mechanical strength, corrosion resistance, and low cost. The article concludes that titanium, titanium alloys, CoCr alloys, and stainless steel are the most commonly used metals for AM of implants due to their high mechanical properties and biocompatibility. Electron beam melting (EBM) and selective laser melting (SLM) are the most popular AM techniques for implant manufacturing, offering high dimensional accuracy and corrosion resistance.

Mohammad Vaezi et.al., [32] The article discusses the limitations of traditional beam-based metal additive manufacturing (AM) technologies, such as high production costs, residual stress, and anisotropic mechanical properties. To address these limitations, beamless metal AM techniques have gained attention in recent years. These techniques offer new possibilities and can fill the gap between industrial production requirements and the qualities offered by traditional beam-based AM technologies. The article reviews the key beamless processes and their latest developments, including sintering-based techniques like binder jetting (BJ), extrusion-based techniques, electrochemical processes like 3DP, solid-state beamless techniques, and cold spray additive manufacturing. And cold spray additive manufacturing. Beamless metal AM techniques offer improved process economics, enhanced mechanical properties, achievable geometries, and surface quality.

Shahir Mohd Yusuf et.al., [33] The article reviews the impact of metal additive manufacturing (AM) on the aerospace industry, highlighting its growth, applications, and challenges. Metal AM has evolved from prototyping to manufacturing propulsion systems and structural components, used in commercial and military aircraft, as well as outer space vehicles. The article discusses the benefits of metal AM in aerospace, including reduced material waste, increased complexity, and improved mechanical properties. The conclusion emphasizes the potential of metal AM to transform the aerospace industry, driving innovation and improvement in product design and manufacturing. Some of the key points from the article include: Metal AM has evolved from prototyping to manufacturing propulsion systems and structural components in aerospace. Metal AM offers benefits like reduced material waste, increased complexity, and improved mechanical properties.

W.S.W. Harun et.al., [34] The article reviews the evolution of metal additive manufacturing (metal-AM) over the past three decades, from its initial use in prototyping to its current mainstream adoption in industries like biomedicine. The review covers recent progress in metal-AM manufacturing technologies, main types of metallic biomaterials, common biomedical applications, and future potential of metal-AM in biomedical research and implementation. The most common metal-based additive manufacturing processes used in biocompatible part production are Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), and Laser Engineered Net Shaping (LENS). The article discusses the benefits of metal-AM, including the production of complex bespoke parts, faster and more cost-effective products, reduced environmental impact, and shortened lead times. Common biocompatible metals used in metal-AM include titanium and its alloys, Co-based alloys, and stainless steel, which offer excellent mechanical properties and biocompatibility.

Mohsen Seifi et.al., [35] The article notes that critical property measurements for AM materials lack standardization, unlike conventional metallic materials. The absence of AM-specific standards and specifications hinders material characterization and qualification. Currently available standards have limitations when applied to metal AM, particularly for measuring mission-critical properties. The authors discuss the importance of standardization efforts for faster and more robust qualification, certification, and device/product certification by regulatory agencies. The article highlights the challenges and future directions for standardization in additive manufacturing, including: Determining the extent of additional AM standardization work needed and the adoptability of existing standards for conventional materials, Understanding the mechanical behavior of AM components, including unique microstructures, residual stresses, material anomalies, and anisotropy, Generating a defects/anomalies catalog with defect definitions.

M.M. Francois et.al., [36] The article emphasizes the importance of microstructure in determining material properties and the need for integrated modeling and simulation to connect process, microstructure, and performance in AM for metals. Current simulation tools are being adapted for AM, requiring models at multiple length scales to account for structural details and physical processes. The article reviews challenges and opportunities in modeling and simulation of AM processes for metals and their mechanical performance, highlighting the need for new modeling and simulation approaches for accurate process and performance representation. A strong linkage with discovery and validation experiments is crucial for advancing the field. The conclusion highlights the vast opportunities in manufacturing science within additive manufacturing, offering economic and defense advantages. These materials offer a rich area for scientific investigation into the process-to-performance linkage for material response.

Mohsen Seifi et.al., [37] The article highlights the need to understand and manipulate process-induced defects and microstructure spatial heterogeneities to produce functional orientation-dependent properties. It also discusses the growing range of metals available for use in AM and the need for further alloy development specifically for AM processing. Challenges that remain include contamination issues, chemistry control during melting and solidification, solidification cracking, lack of understanding of processing-structure-property relationships, insufficient testing, and lack of shared knowledge and materials test results across the AM community. The article concludes that traditional statistically-based qualification processes for metallic materials are not practical for AM due to the high variability in processes and processing parameters.

Adrian Uriondo et.al., [38] The article reviews recent improvements in additive manufacturing (AM) technologies for producing and repairing metal parts in the aerospace industry. It focuses on electron beam melting, selective laser melting, and other metal deposition processes, such as wire and arc additive manufacturing. The article highlights the benefits of AM, including reduced production ramp-up time and cost, feasibility of small production batches, and capability to produce complex geometries. However, it also notes technical challenges, such as machine-to-machine variability, need for industry specifications and standards, and development of new alloys and design guidelines. The article concludes that implementing AM in the aerospace industry is challenging due to the high regulatory framework for ensuring airworthiness.

D D Gu et.al., [39] The article highlights the metallurgical mechanism of LS, which involves rapid solidification and a semisolid consolidation mechanism (liquid phase sintering). It emphasizes the importance of determining powder characteristics and laser processing conditions to achieve favorable metallurgical mechanisms. The article concludes that AM technology has reached a mature growth stage and is competitive with traditional manufacturing techniques. It highlights future research interests, including extending AM applicable powders, developing novel materials, establishing an AM process database, understanding microstructure development, and theoretical modeling and simulation of AM processes. LS, LM, and LMD processes can produce complex-shaped functional metallic components for various industries. Material characteristics, processing conditions, and metallurgical mechanisms are crucial for achieving favorable microstructural and mechanical properties.

Lawrence E. Murr et.al., [40] The article emphasizes the potential of these technologies to create functional metal systems with tailored properties and performance, including unique microstructures, high specific strength and stiffness, and customizable relative density and stiffness. The article delves into the microstructural features of Ti-6Al-4V components fabricated using EBM and SLM techniques, showing how different processing conditions and scanning strategies can influence the microstructure, leading to variations in grain growth, phase transitions, and mechanical properties. The article concludes that additive manufacturing using EBM and SLM is a revolutionary technology for metal fabrication, allowing for the creation of complex, multi-functional products with controlled microstructural architectures. Some of the key points from the article include: Additive manufacturing technologies, such as SLM and EBM, enable the rapid fabrication of complex, multi-functional metal or alloy components. These technologies allow for the creation of unique microstructures and properties, including directional growth features, multiscale hierarchical structures, and high specific strength and stiffness.

I. Conclusion

An Overview of Metal Additive Manufacturing is Given in This Review. It also talks about the difficulties and constraints that manufacturers and researchers have implementing material extrusion for metal additive manufacturing. The Additive Manufacturing (AM) Sector Has Advanced Significantly, With High-Value Industries Seeing an Increase in Metal AM's Popularity. This is challenging because of differences in suppliers, machines, and processes. Notwithstanding these obstacles, metal additive manufacturing has advanced significantly and is becoming more and more common in high-value sectors like medical implants and aircraft. To overcome current obstacles and realize the full potential of metal additive manufacturing, the Paper Reviews on the Further Research are essential and to overcome current obstacles and realize the full potential of metal additive manufacturing (AM), more research is essential. In the end, metal additive manufacturing is a key factor in promoting efficiency and innovation in important industries, and its further advancement will be necessary to influence the direction of manufacturing. The technology's use in orthopedic, dental, and craniofacial implants has increased because to its capacity to create porous, light-weight, and load-bearing structures. In the production of unique and desired shapes, medical implants, and the aerospace industry, metal additive manufacturing plays a crucial role.

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