Study of Additive Manufacturing of Composite Materials an Overview

Rajneesh Kumar, Aditya Veer Gautam, Anurag Kumar, Shivangi Dixit
Faculty of Engineering and Technology, Rama University
rajkum2288@gmail.com

Abstract

In this paper, the author discusses the use of lightweight composite materials across several industries, including aerospace, automotive, nuclear, marine, and biomedical fields. These materials, known for their robust mechanical properties and tailored performance, include Polymer Matrix Composites (PMC), such as fiber-reinforced polymers, and Metal Matrix Composites (MMC), such as aluminum matrix composites and titanium-aluminum-based composites. A major challenge in the industry is the efficient production of these composites. Additive Manufacturing presents a promising solution for creating innovative and intricate parts from composite materials. This paper provides a comprehensive review of various Additive Manufacturing techniques applicable to both Polymer Matrix Composites and Metal Matrix Composites.

Keywords: Additive Manufacturing, Composite Materials, Lightweight Structures
DOI Number: 10.48047/nq.2021.19.2.NQ21062 NeuroQuantology 2021; 19(2): 380-385

1. Introduction: Industrial Demand for Composite Materials

Composite materials, which are made by combining two or more materials, are frequently utilized in creating lightweight components and structures across various industries. Notably, they are extensively used in the aerospace sector, where they play a significant role in manufacturing numerous aircraft components. As of recent data, composite materials comprise about 50-60% of an aircraft's airframe. Additionally, since 2015, the automotive industry has seen a 5% annual growth in the use of composites. In 2015, the global market demand for these materials reached approximately $22.2 billion.

These materials are popular in a range of applications, particularly in transportation, construction, automotive, and aerospace fields, due to their excellent mechanical properties, design flexibility, cost-effectiveness, and superior performance.

2. Literature Review: Additive Manufacturing (AM) Processes

According to ISO/ASTM 52900, Additive Manufacturing (AM) is described as a process that involves joining materials to create parts based on 3D model data, typically by adding material layer by layer. This differs from subtractive and formative manufacturing methods. The types of AM processes are categorized based on the state of the raw material used, which include liquid, molten, powder, and solid layer forms provides numerous benefits compared to conventional manufacturing techniques such as casting and machining Rapid product development process:-

a. High degree of customization
b. Complex designs
c. High level of automation

Various researchers have been reported fabrication composite materials using various AM processes.

These processes include; Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Direct Energy Deposition (DED), and Stereo lithography (SLA).

This work presents an overview of the development of AM processes which are used for fabricating composite materials with using different material.

FDM is an AM process in which two separate nozzles i) one for model material and Iii) second for support material, are used to build a 3D model designed using a CAD tool. In a typical FDM system, the build or raw material is melted and deposited from the build nozzle to develop the part layer-by-layer. The carrier material is added to each layer to help the built layer but it needs to be removed at the end of the final process. Figure 1b shows a schematic diagram for a typical FDM system.

SLS/SLM is a powder-bed process in which a powder is distributed and spread with a coater arm to create a level, uniform surface that completely covers the projected/habitation area. A carbon dioxide or Ytterbium fiber laser is then precisely directed at the powder layer and scans over the cross-section of the part as shown in Figure 1a. The build platform is then lowered and the process is repeated until all layers have been printed.

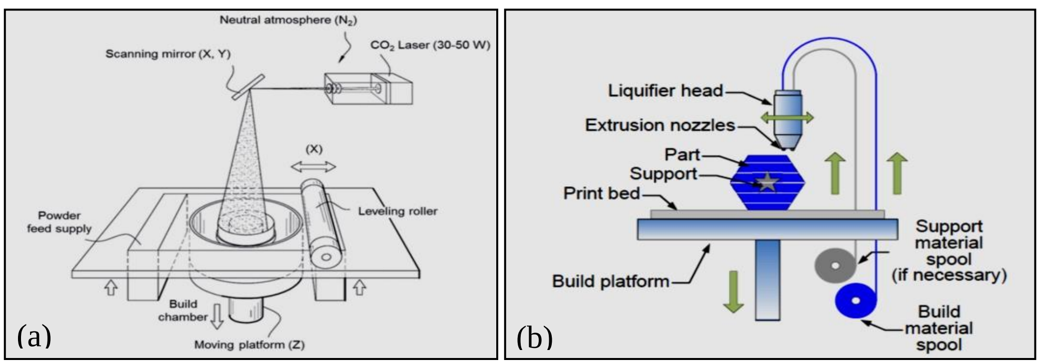

Figure1:-Schematic Diagram of the (a) SLS Processand (b) FDM Process

DED includes two techniques; i) powder-based (3D cladding) and ii) wire-based (3D welding). Powder-based DED is an AM process in which a metal powder is deposited through a nozzle and melted using a laser/electron or plasma beam to form a layer as shown in Figure 2a. The laser-based method is referred to as Laser Metal Deposition (LMD), Direct Metal Deposition (DMD), Laser Engineered Net Shaping (LENS), and Laser Consolidation (LC). LMD or LC occurs through the process of a

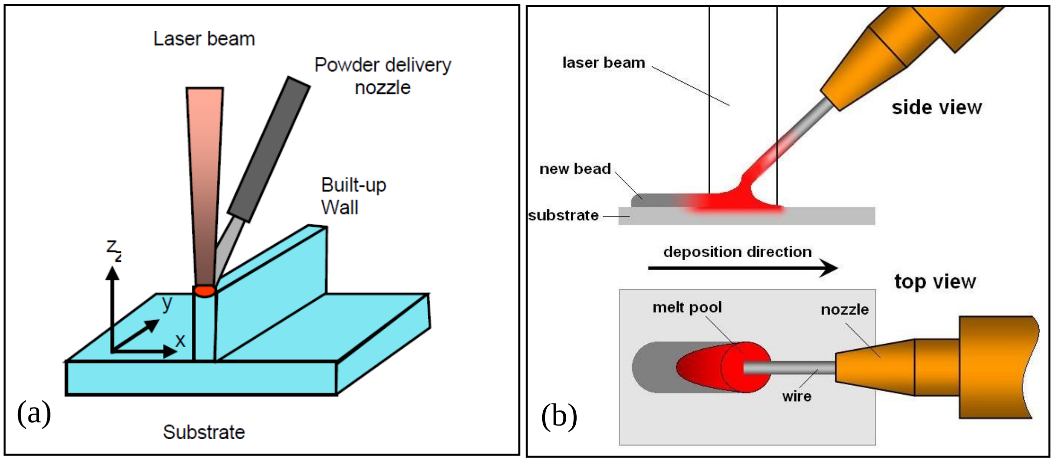

Figure 2:-Schematic Illustration of the DED Process: (a) Powder-Based and (b) Wire Based

Nozzle feeding metal powder that is subsequently laser melted onto the substrate layer. The plasma-based method, which is called Plasma Deposition Manufacturing (PDM), starts by supplying a continuous powder feed to a plasma-melted zone in an inert gas environment composed of argon, helium or nitrogen, to help reduce oxidation. In wire-based DED, a wire of small diameter is fed and melted, binding to the previous layers through welding as shown in Figure 2b. It is commonly known as Shaped Metal Deposition (SMD). SMD is particularly noteworthy because it can use a wider range of metals than laser deposition or electron beam welding. DED is particularly relevant because it can use a wider range of materials. It is commonly used for fabricating polymers, metal/polymer composites, and metals. The resolution of the process is dictated by the wire thickness and material. DED is a very versatile process that has the unique ability to repair metal parts that cannot be repaired by any other conventional methods. This process can coat, build, and rebuild very complex components from laser-consolidated materials such as nickel-based super alloys, cobalt alloys, titanium alloys, and steels. This process also boasts very dense and large parts with mechanical properties that are competitive with cast material.

SLA is an AM technology which converts liquid photosensitive resin into a solid state by selectively exposing a resin vat to ultraviolet (UV) light. Layers are made one by one as the building platform lowers after each layer is fully completed.

3. Additive Manufacturing of Composite Materials

This paper deals with the AM of lightweight composites, in particular Polymer Matrix Composites (PMCs) and Metal Matrix Composites(MMCs). Composite materials typically consist of; i)a matrix as a continuous phase,ii) a reinforcement as a discontinuous or dispersed phase, and iii) an interface or binder. Composite materials various properties like mechanical strength, characteristics ad microstructure can be controlled through the proper selection of the constituent materials and the fabrication method. AM is capable for multi-directional fabrication and free form fabrication. Hence, AM could be an effective fabrication method of multi-directional performs for composite materials. Polymers and lightweight composites are used in many applications including the aerospace industry.

Additive Manufacturing of Polymer Matrix Composites (PMCs) the literature showed various attempts to additively manufacture polymer matrix composites (PMCs) for the fabrication of complex designs and structures are usually fabricated using FDM, SLS, DEDand SLAprocesses.

The FDM process is used for fabricating fiber-reinforced polymers because it allows the addition of the reinforcement in a fiber form. It allows the addition of carbon fibers into a plastic matrix. Fiber-reinforced PMCs fabricated by FDM showed footprints of the fibers on the fractography of the tensile-test surfaces as shown in Figure 3a. The use of FDM in producing carbon-fiber polymers allows an increase in the tensile strength and a decrease in the toughness and ductility. One of the challenges in SLS of PMCs is to have a uniform mixture between the matrix and the reinforcement. The percentage of reinforcement weight affects the amount of energy density required for melting as shown in Figure 3b.

The DED process is similar to the SLS process except that it is a powder-fed process while SLS is a powder-bed process and SLA can be used to fabricate PMCs but with less mechanical properties .

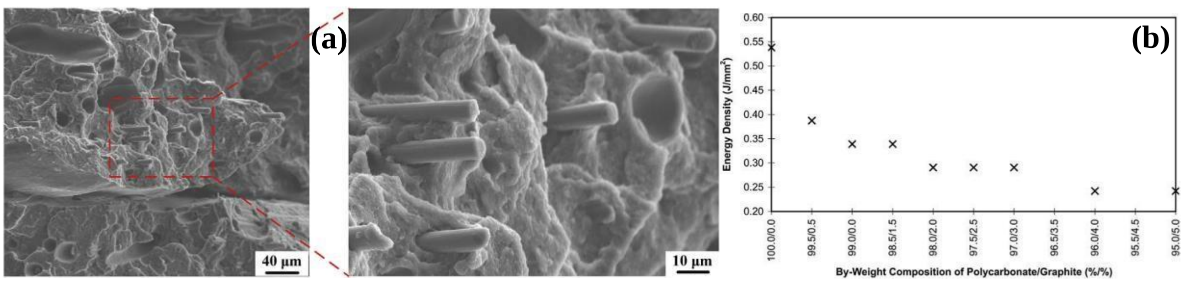

Figure3:-(a) Scanning Electron Image of the Fractography of the Tensile-Test Surfaces [16], and *(b) Effect of Reinforcement Composition on the Laser Energy Density*

Additive Manufacturing of Metal Matrix Composites (MMCs).Recent studies showed various Metal-Matrix Composites (MMCs) (i.e. aluminum- matrix, titanium-matrix, and Ti-Al-matrix composites) that have been fabricated by SLM, FDM, and DEDprocesses. The reinforcement iseither particulates in the form of powder or fiber in the form of filament. Graphite, silicon carbide, titanium carbide, and tungsten carbide are commonly used in AM of MMCs.

The effect of the SLM process parameters on the mechanical properties of the titanium carbide Ti-C reinforced AlSi10Mg matrix. Figure 4a and Figure4b show the microstructures of the enforcement and the matrix powder. Another study on the SLM of titanium carbide reinforced titanium matrix. Figure4c shows the homogeneously mixed titanium carbide with titanium. Some researchers were conducted to select the “optimum” process parameters to fabricate composite materials. Developed a suitable set of SLM process parameters for fabricating Ti-Al alloy. Figure 5 shows different morphologies obtained at different SLM process parameters. Balling, unstable melting, and cracks could occur at different process parameters with examined the use of powder-based DED process to fabricate Ti-Al alloys with better microstructures.

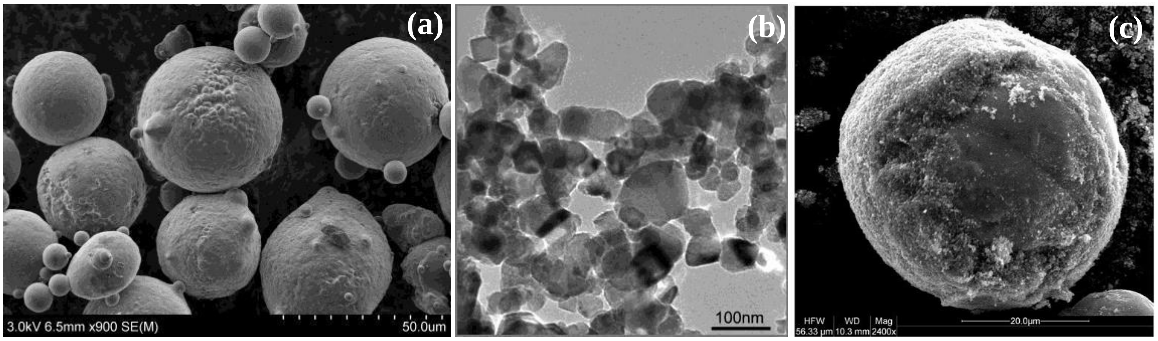

Figure4:-Microstructure of (a) AlSi10Mg Powder (Matrix), (b) Ti-C Powder (Enforcement), and (c) Mixture of Titanium (Matrix) and Ti-C (Enforcement)

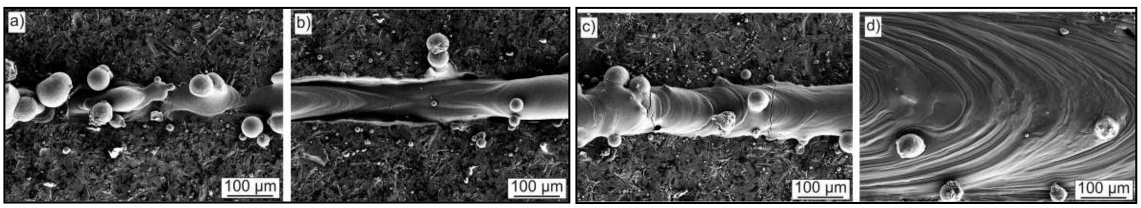

Figure5:-Morphologies of Ti-Al Parts produced by SLM at Different Process Parameters:Balling, (b) Unstable melting, (c) Cracks, and (d) Stable Melting

Generally, additive manufacturing (AM) of composite materials encounters several challenges. These include maintaining a consistent distribution of reinforcing material within the matrix, ensuring the availability of feedstock material in suitable forms (wire or powder), and addressing defects that may arise from chemical variations in the feedstock materials. Additionally, determining the optimal process parameters for fabricating composite materials is crucial, as inadequate parameters can lead to changes in material microstructure during the process, affecting the mechanical properties of the produced parts. Consequently, addressing these challenges is essential for the sustainable development of additive manufacturing techniques for composite materials.

Conclusions

The primary challenges associated with using AM technology for fabricating composite materials include ensuring the proper form of the feedstock (either wire or powder) and determining the appropriate process parameters to produce dense composite components with desirable mechanical properties. Further research is required to identify the optimal process parameters for fabricating composite materials effectively. This paper provides an overview of the AM processes utilized in manufacturing both Polymer-Matrix and Metal-Matrix Composites, including Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Direct Energy Deposition (DED), and Stereo lithography (SLA). It also summarizes some findings from existing literature to highlight areas for future research.

References

1) F. C. Campbell, Lightweight Materials: ASM International,2012.M. Zhou, R. Fleury, and M. Kemp, "Optimization of Composite: Recent Advances and Application," Altair Engineering Inc.2011.
2) S. Mazumdar, "State of the Composites Industry," in Basalt. Today, ed,2016.ISO/ASTM52900, "Standard Terminology for Additive Manufacturing – General Principles – Terminology," ed: ISO/ASTM International,2015.
3) N. GUO and M. C. LEU, "Additive Manufacturing: Technology, Applications and Research Needs," Frontiers of Mechanical Engineering, vol. 8, pp. 215-243, 2013.
4) I. Gibson, D. Rosen, and B. Stucker, Additive Manufacturing Technologies; 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing: Springer, 2015.
5) K.V.WongandA.Hernandez,"AReviewofAdditiveManufacturing,"International Scholarly Research Network (ISRN) vol. 2012, 2012.
6) H. A. Hegab, "Design for additive manufacturing of composite materials and potential alloys: a review," Manufacturing Review, vol. 3, 2016.
7) Z. Quan, A. Wu, M. Keefe, X. Qin, J. Yu, J. Suhr, et al., "Additive manufacturing of multi-directional performs for composites: opportunities and challenges," Materials Today, vol. 18, pp. 503-512,2015.