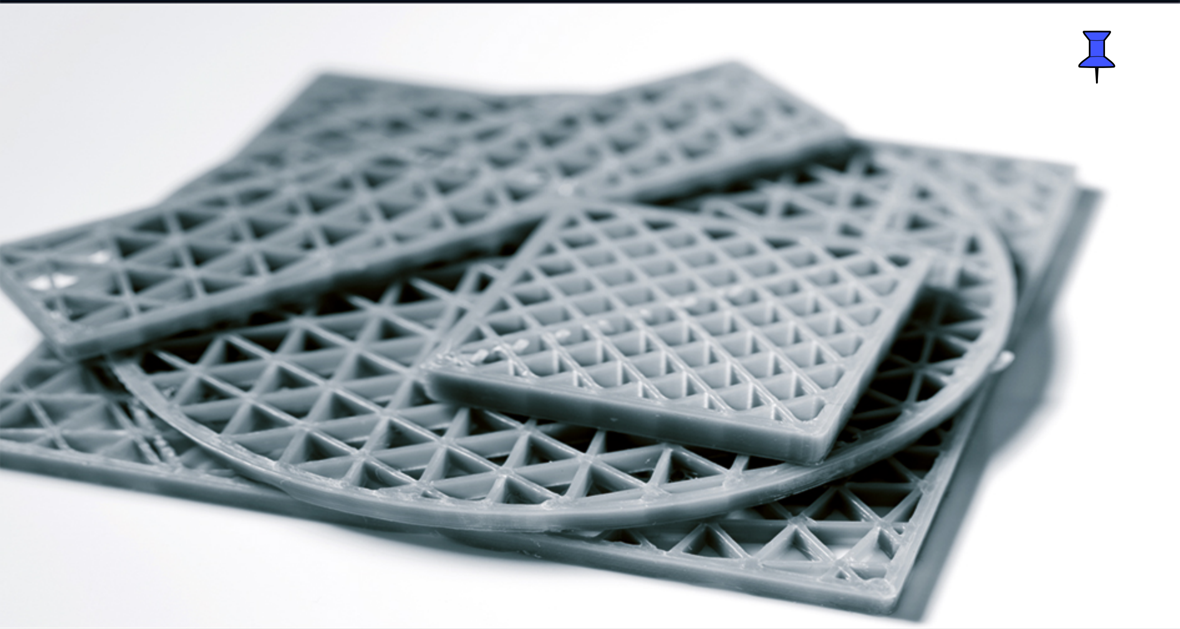
MATERIALS SCIENCE



Light Weight Materials

Processing and Characterization

Edited by
Kaushik Kumar
Bathini Sridhar Babu
J. Paulo Davim

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Preface

We would like to present the book *Light Weight Materials: Processing and Characterization*. In the automotive industry, the need to reduce vehicle weight has led to extensive research efforts to develop aluminum and magnesium alloys for structural car body parts. In aerospace, the move towards composite airframe structures has led to an increased use of formable titanium alloys. All of the above-mentioned materials can be categorized into a group called "*lightweight materials*". The distinguishing feature of lightweight materials is their low densities, ranging from as low as 0.80 g/cm^3 for unfilled polymers to as high as 4.5 g/cm^3 for titanium. Although the density of titanium is higher than that of unfilled polymers, it is significantly lighter than metals: alloy steel (7.86 g/cm^3) and superalloys (7.8–9.4 g/cm^3). In a nutshell, lightweight materials exhibit a wide range of properties and therefore offer a wide range of applications.

This book primarily aims to provide researchers and students with an overview of the recent advancements in the processing, manufacturing and characterization of lightweight materials, which promises increased flexibility in manufacturing in tandem with mass communication, improved productivity and better quality. It has a collection of chapters contributed by eminent researchers who focus on the topics associated with lightweight materials, including the current buzzword *composite materials*. This book provides the recent advancements in the processing, manufacturing and characterization of lightweight materials and hence would be a panacea in all areas of lightweight materials.

This book has two major objectives. Firstly its chapters by eminent researchers in the field enlighten readers about the current status of the subject. Secondly, as the densities vary a lot so do the applications ranging from automobile, aviation to bio-mechatronics; hence, this book would serve as an excellent guideline for people in all of these fields.

The chapters of this book are divided into three parts, namely Part 1: Manufacturing Processing Techniques, Part 2: Characterization and Part 3: Analysis.

Part 1 contains Chapters 1–3, Part 2 contains Chapters 4 and 5 and Part 3 contains Chapters 6–8.

Chapter 1 explains an advanced technique called *additive manufacturing* (AM), which is predominantly known as 3D printing and rapid prototyping. It is an on-demand production without any dedicated apparatus or tooling, which allows breakthrough performance and supreme flexibility in industries. The aerospace industry is the primary user of AM, as it enables it to create complex user-defined part design and fabricate with different lightweight materials without wastage of raw materials, reducing the time and cost of production. This chapter provides in-depth knowledge about its classification and selection process for various applications required by engineering industries, especially in the aerospace industry.

Chapter 2 mainly deals with the manufacturing of polymer gears. Polymer gears are widely used in medical devices upon which human lives depend. In addition, they are useful in other applications such as in the automotive and manufacturing industries. A precise gear of better design and effective manufacturing process decides its long-term application, strength and property. Polymer gears can be fabricated with the same machining process as metal gears, usually milling or hobbing from a blank. However, for lightweight materials, such as polymers, it is preferable to be either fabricated by injection molding or machined from a rod (additive manufacturing). The details of such manufacturing techniques are presented in this chapter.

Chapter 3, the last chapter of Part 1, discusses in detail reinforcing, performance analysis, processing and characterization of various methods of polymer welding, i.e. laser welding, infrared welding, spin welding, stir welding, and vibration welding. This chapter also covers various alloys of aluminum for lightweight applications and the current status of polymer composite applications in industries and future prospects. This chapter highlights the complications related to fusion, heat transfer and joint strength, as well as their solutions with the future prospect of polymer welding empowering polymers to be an absolute substitute for metal, which can be achieved by understanding the concept of dissimilar welding for joining polymer composites with metals and their controlling factors, and by selecting an appropriate welding process for various types of polymers.

Chapter 4, the first chapter of Part 2, provides the reader with an idea of fabrication and a description of the processing techniques of natural-based composites for light body vehicle applications. In doing so, the genetic equation for modeling tool flank wear is developed using experimentally measured flank wear values and genetic programming. Using these results, the genetic model presenting the connection between cutting parameters and tool flank wear is extracted. Then, based on a defined machining performance index and the obtained genetic equation, optimum cutting parameters are determined. This chapter concludes that the proposed modeling and optimization methodology offer the optimum cutting parameters and can be implemented in real industrial applications.

Chapter 5 presents the response surface methodology, an optimization technique, to design a catalytic cracking experiment of plastic waste. The catalyst-to-feedstock ratio, the operating temperature and the reaction time were chosen as an effective parameter of the catalytic cracking process. The characterization of the obtained liquid product was performed using the Fourier transform with infrared (FTIR) spectra, gas chromatography with mass spectrometry (GC/MS) analysis and physico-chemical analysis. This chapter concludes that the developed quadratic model is well fit to the experimental domains and predicts operating conditions that are most suitable for conducting catalytic cracking experiments under recycling techniques of lightweight materials, especially plastics.

Chapter 6, the first chapter of Part 3, discusses laser welding. The uniqueness of this chapter is the way it has dealt with the subject. The finite element analysis was used to select suitable models for the Gaussian beam profile and the application of the Frustum model to conduction mode welding and keyhole laser welds. Temperature and stress analysis was carried out within and around the weld region. This chapter discusses the analytical comparative approximation of different model approaches applicable to the laser weld process, and indicates that the parametric study information will be useful to the engineers of nuclear fabrication applications in finalizing different components.

Chapter 7 elaborates on the effect of formability parameters on tailor-welded blanks of lightweight materials. The product finds its maximum application in the automotive manufacturing industry. It is quite common that different materials with varying cross-sections are used based on the requirements in aerospace and automotive industries. To manage the herculean task of organizing this, researchers have enthusiastically proposed a tailor-made welded blanks (TWB) strategy, and in many automotive industries this technique has been adopted. This chapter suggests testing the formability of tailor-welded blanks with various light alloy sheets used in the aerospace and automotive industries. An overall review of various parameters that affect the formability of tailor-welded blanks is presented in this chapter, so that other investigators can rely on the same for more critical observations in this field.

Chapter 8, the last chapter of this section, presents the various ways of optimizing a vehicle body, such as shape optimization for aerodynamics and aesthetics, and weight of materials to be used for fuel efficiency, material conservation, recyclability and others. This chapter considers a product called “B-pillar”, one of the critical structural support members of sedan cars. They have replaced the existing material with a composite, mainly to overcome the stress developed due to the system as it is a structural member and to safeguard the occupant in the case of a side crash. Different mechanical properties such as tensile, compression and bending strength, as well as water absorption, were measured. The model of the sedan car B-pillar panel developed was analyzed for impact and crush simulation. It concluded that a composite can be used for the outer panel of B-pillar, which results in reduced vehicle weight and fuel consumption and increased energy absorption.

First and foremost, we would like to thank God. It was your blessing that provided us with the strength to believe in passion and hard work and to pursue our dreams. We thank our families for having the patience with us for taking yet another challenge that decreased the amount of time we could spend with them. They are our inspiration and motivation. We would like to thank our parents and grandparents for allowing us to follow our ambitions. We would like to thank all the contributing authors, as they are the pillars of this structure. We would also like to thank them for believing in us. We would like to thank all of our colleagues and friends in different parts of the world for sharing their ideas helping us to shape our thoughts. We will be

satisfied with our efforts when the professionals concerned with all the fields related to lightweight materials are benefitted.

We owe a huge thanks to all of our technical reviewers, Editorial Advisory Board members, Book Development Editor and the team at ISTE Ltd for their availability to work on this huge project. All of their efforts helped us to complete this book, and we could not have done it without them.

Last, but definitely not least, we would like to thank all of the individuals who have taken time out and helped us during the process of editing this book. Without their support and encouragement, we would have probably given up the project.

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September 2020

PART 1

Manufacturing Processing Techniques

Light Weight Materials: Processing and Characterization,
First Edition. Kaushik Kumar; Bathini Sridhar Babu and J. Paulo Davim.

1

Additive Manufacturing: Technology, Materials and Applications in Aerospace

Additive manufacturing (AM), predominantly known as 3D printing, is transmuting product design, production and service. AM assists us in achieving on-demand production without dedicated apparatus or tooling, unlocks digital design tools, and leads to breakthrough performance and supreme flexibility in industries. Knowledge acts as a barrier to this technique since the selection process for various materials and their applications and requirements differ from each individualized processes. The aerospace industry is the primary user of AM, as it enables it to create complex user-defined part design and fabricate with different materials without wastage of raw materials, reducing the time and cost of production.

This research work promotes the clarity of AM technology by providing in-depth knowledge about its classification and selection process for various applications required by engineering industries, especially in the aerospace industry. Several 3D printing methods and the use of different materials and their applications in the aerospace industry are discussed in detail.

Chapter written by Veeman DHINAKARAN, Mahesh VARSHA SHREE, Thimmaiah JAGADEESHA and Madabushi SWAPNA SAI.

1.1. Introduction

Additive manufacturing technology enables a variety of innovative and economically reliable components when compared to conventional manufacturing methods. The term "rapid prototyping" (RP) is defined as the emphasis of generating a design for a prototype or a base model at a faster rate to promote the end product for manufacturing. It is used in various industries to rapidly develop various peripherals with intricate user-defined models into a commercialized product (Devadiga 2017). RP technology emerged as the first methodology for making user-defined models, but it lags behind modern methodology due to its inadequate efficiency to effectively create products within the time limit and cost of production. Additive manufacturing (AM) technology developed from RP technology to enhance the quality of the output product. AM acts as a basic principle of creating three-dimensional (3D) objects generated through computer-aided design (CAD) systems. In AM technology, the components are produced from CAD data and slicing software to create a specified part geometry rather than complex tooling and additional fixtures that are used in conventional manufacturing methodologies. In AM technology, the structures are built in a layer-by-layer fashion with a specified cross-section, which is not only used in manufacturing industries to fabricate automobile components and dynamic mechanical structures but is also used in tissue engineering with the capacity of bioprinting to create biomedical implants, artificial human organs and drug delivery systems (Herzog 2016). AM technology acts as a key to solving environmental and engineering issues since it has free-form fabrication (FFF) that facilitates producing user-defined geometries with all classes of raw materials without any limitations, unlike metals, non-metals, alloys and synthetic polymers, with no wastage of materials. This technology can be further improved by increasing its applications across the engineering industry (Dhinakaran 2019). There are numerous stages involved in product development, initially from generating a CAD model to the conversion of the STL file format to make the end product (DebRoy 2018). As AM is a multi-purpose method, it is used not only for producing new components but also to simplify and alter the existing components.

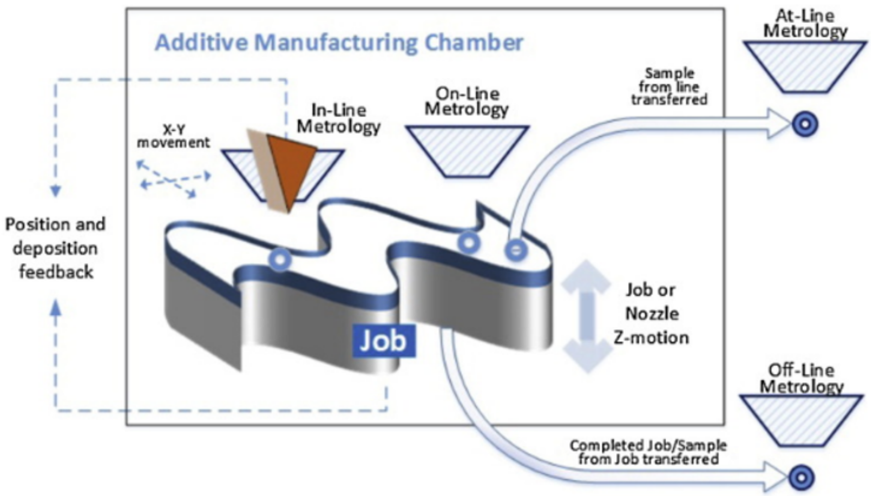

Figure 1.1. *Additive manufacturing process (Tofail 2018). For a color version of this figure, see www.iste.co.uk/kumar/materials.zip*

1.2. Additive manufacturing configuration

AM technology uses specialized designing software to produce CAD models with user-defined cross-sections and process constraints such as material restraints, source of energy, timings and layer thickness. The computed CAD design is then formatted into an STL (stereolithographic) file format. The STL file displays the peripherally closed external surface of the CAD geometry and performs the slice calculation using a slicing software, and then it is sent to the AM machine which is verified for its build orientation and position (Brandsmeier 2017). The construction of the material is automatically carried out in a layered fashion by the machine (3D printer) without any human supervision. The 3D printer needs manpower to only monitor the availability of raw materials and to check for any run-time errors. After completing the product, the interaction of the part with the machine is cut down by adjusting the machine temperature and then detached. In post-processing, the part is cleaned before use and treated mechanically for surface finish and the required texture (Scheck 2016).

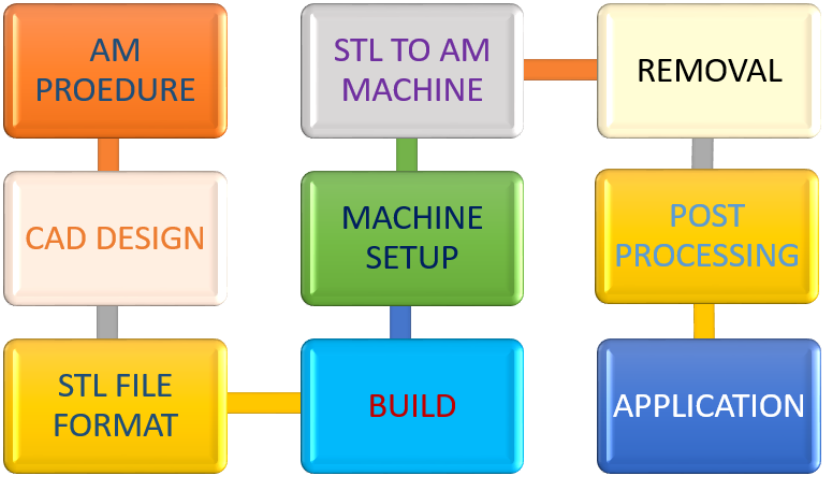

Figure 1.2. *Additive manufacturing procedure. For a color version of this figure, see www.iste.co.uk/kumar/materials.zip*

1.3. Classification of AM technology

The diversity of materials has convoluted the 3D structures being fabricated with a distinct class of functional time and assembly. AM technology emerged as a great boon over conventional methodologies for creating complex geometries (Ngo 2018). The prominent process of AM is classified into the following seven types:

– laser beam melting;

– electron beam melting;

– selective laser melting;

– direct metal laser sintering;

– laser metal fusion;

– direct metal deposition.

1.3.1. *Laser beam melting*

The laser beam melting (LBM) technology uses a laser beam to fuse the succeeding layers of metal powders, which are suitably used in thin-walled, small-scale structures to build a 3D part from the powder bed. In this method, a CAD model is first converted into an STL file and then sliced into a 2D element; at each layer, the powder bed is sintered by distributing the layers of powder throughout the building platform using a laser beam. The above-described process is simultaneous and stops after the completion of the product. This method is suitable for metals, polymers and ceramics (Bayerlein 2018). LBM produces strong parts due to its reduced porosity and controlled crystal structure.

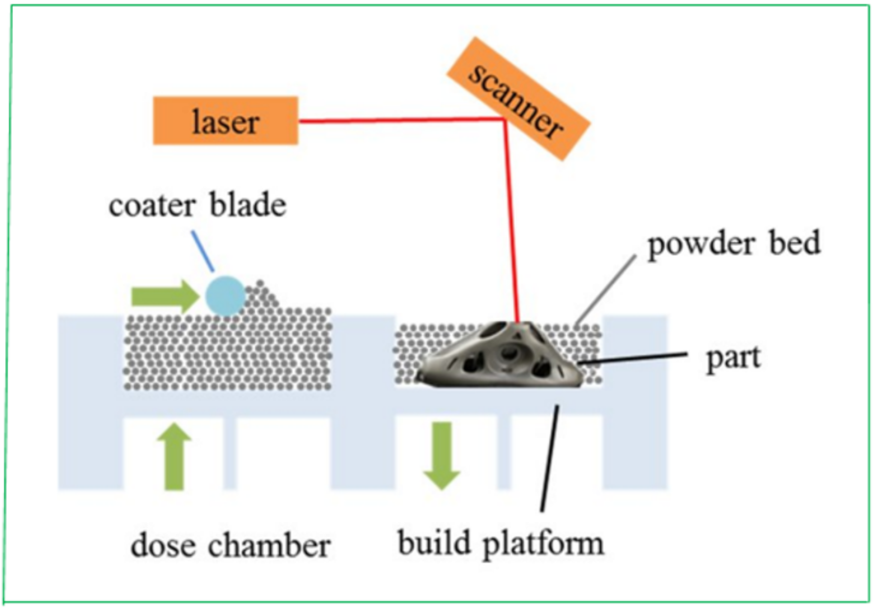

Figure 1.3. *Laser beam melting technology (Anderl 2014). For a color version of this figure, see www.iste.co.uk/kumar/materials.zip*

1.3.2. *Electron beam melting*

In electron beam melting (EBM), the raw material is fused together by heating an electron beam under vacuum, which are used to build metallic components, especially in aerospace industries. In this method, a beam of electron acts as a heat transmission source that has a higher melting capacity, as well as productivity, which are controlled by electromagnetic coils, thereby allowing the melting of metals into a solid geometry. The EBM machine obtains input data from a CAD model and builds the part under vacuum (Zhao 2016). It is used to manufacture standard metal parts such as fixtures, prototypes and support structures in a slow and cost-effective process.

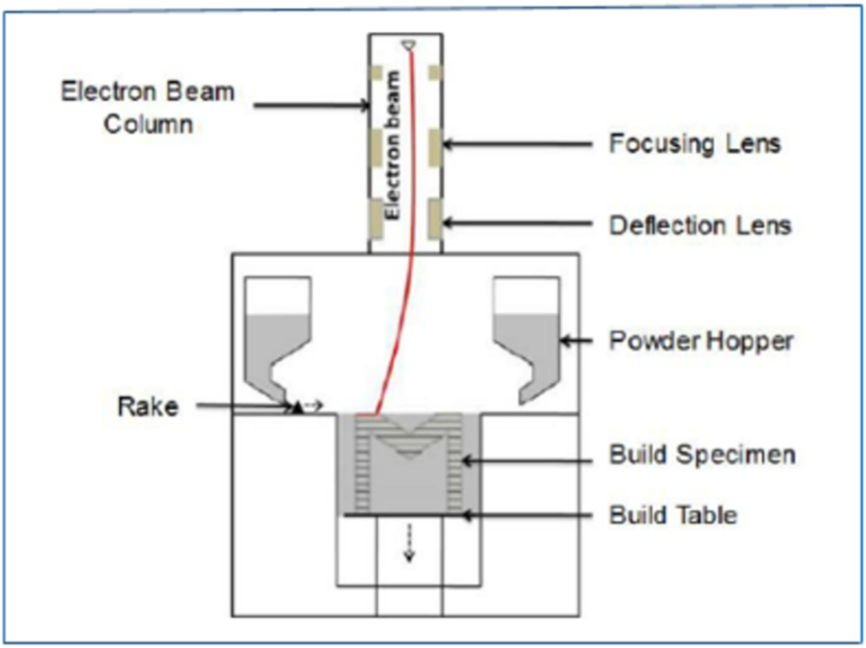

Figure 1.4. *Electron beam melting (Mandil, 2016). For a color version of this figure, see www.iste.co.uk/kumar/materials.zip*

1.3.3. *Selective laser melting*

Selective laser melting (SLM) uses a high-power density laser to melt the raw material and fuse it together with metallic powders, which is mainly used for low-volume materials. In this technique, various materials such as glass, ceramics and plastics are used. The laser beam will heat the particles at appropriate positions on a bed of metallic powder until it is completely smelted. The AM machine will consecutively increase the melted layers over the metal bed until it reaches the expected design (Jürgen 2017). Its common applications can be found in aerospace industries, automobile industries and medical industry to overcome the demand for human organs.