Additive Manufacturing Skills in Practice Series

Fundamentals of Additive Manufacturing for the Practitioner

SHEKU KAMARA · KATHY S FAGGIANI

WILEY

FUNDAMENTALS OF ADDITIVE MANUFACTURING FOR THE PRACTITIONER

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Contents

Chapter 1 Introduction: Moving into Additive Manufacturing 1

Introduction 2
Manufacturing Processes 5
Traditional and AM Job Roles 8
How to Use This Book 20
References 20

Chapter 2 Is Additive Manufacturing the Right Solution? 21

Introduction 22
Additive Manufacturing Applications 23
A Brief History of AM 33
Selecting a Pilot AM Project 35
References 41

Chapter 3 What Design and Inputs Does Additive Manufacturing Require? 43

Introduction 44
Design for AM 45
Design for DFAM 45
Component Design 47
Part Design 50
Process Design 57
Sources of Input 58
AMF and STL File Formats 59
References 63

Chapter 4 What Materials Does Additive Manufacturing Use? 65

Introduction to AM Materials 66
Selecting AM Materials 67
Polymers 69
References 82

Chapter 5 Which Additive Manufacturing Technology and Process Are Right for My Solution? 85

Introduction 86
Binder Jetting 88
Directed Energy Deposition 90
Material Extrusion 92
Material Jetting 94
Powder Bed Fusion 96
Sheet Lamination 98
Vat Photopolymerization 99
Hybrid Systems 102
References 103

Chapter 6 What Machine and Build Preparation Occurs in Additive Manufacturing? 105

Introduction 106
General Machine and Build Preparation Tasks 107
AM Process-Specific Machine and Build Preparation 111
References 122

Chapter 7 What Occurs During the Additive Manufacturing Build Process? 123

Introduction 124
Quality in AM 124
Build Planning and the Build Process 128
Build Process 133
References 138

Chapter 8 What Happens after the Additive Manufacturing Build Process Is Complete? 141

Introduction 142
Part Removal 143
Material Removal 144
Support Removal 146
Treating 147
Finishing 147
Inspection 148
Summary of Post-Processing Methods 148
References 150

Chapter 9 What Do We Do to Move to Additive Manufacturing? 153

Introduction 153
AM Implementation Roadmap 154
Identify a Vision and Strategy 155
Prepare to Manage Change 157
Acquire AM Systems Access and Support 158
Develop AM Workflows 161
Develop Your AM Workforce 162
Monitor Results and Adjust 164
References 165

Chapter 10 Where Can I Learn More? 167

Introduction 167
AM Acronyms and Terminology 167
AM Job Postings and Employment Information 168
AM Education and Training 169
AM Professional Certification 170
AM Body of Knowledge (AMBOK) 170
AM University Consortia and Centers of Excellence 171
AM Service Bureaus and Vendors 171
AM Material Selection Guides 172
AM Technology Selection Guides 172
AM Design Guidelines 173
AM Professional Associations, Conferences, and Meetings 173

Index 175

Chapter 1

Introduction: Moving into Additive Manufacturing

Case Introduction: Current work roles in manufacturing and how they change in AM

Great West Manufacturing (GWM), a medium-size manufacturing firm, recently experienced a change in leadership. The board of directors has charged the new CEO, Sherman Potter, to explore and implement additive manufacturing (AM) to better prepare the firm for long-term viability in their increasingly competitive manufacturing space. The new CEO has made it clear that GWM will continue to manufacture the current line of recreation and athletics end-user products but would like to expand operations to include new opportunities facilitated by AM. As part of the exploration effort, Potter assigned Pete Granger (manufacturing process engineer), Bob Nelson (design and materials engineer), Edgar Remmins (manufacturing technician), and Roxanne Jensen (compliance, testing, and quality control engineer) to the AM Pilot Project team. Their charge is to investigate the knowledge and skills

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needed to support additive manufacturing at GWM and formulate a plan to conduct an additive manufacturing pilot test at GWM.

In their first meeting, each team member revealed that s/he had minimal understanding of additive manufacturing with some familiarity with 3D printing concepts. The team's experience in traditional manufacturing ranged from 2 to 24 years in their respective career areas. The group decided to start by preparing a list of GWM's manufacturing roles and responsibilities to compare current talent to the knowledge and skills needed for additive manufacturing. Their focus would then shift to exploring additive manufacturing and 3D printing (AM) requirements and processes in preparation for developing a proposal to initiate a pilot project within GWM.

INTRODUCTION

Imagine the year is 2025. The world has quelled COVID-19, the United States has convinced many American manufacturers to move production back to the states, and focused financial investments have spurred significant ongoing growth in the manufacturing sector. Simultaneously, the manufacturing workforce has suffered a hit from the loss of seasoned employees through retirement. Manufacturing has had limited success in recruiting high school and college graduates and is struggling to find employees with the right skillsets to advance additive manufacturing and other emerging production approaches. Fortunately, many great opportunities for exciting work and career growth exist for those who choose a manufacturing career path. While you may have significant experience in different aspects of manufacturing as a manufacturing practitioner, are you ready to meet the challenge of implementing additive manufacturing technologies and processes in the next four to five years?

In the early 1980s, Chuck Hall produced the first stereolithography part, and the following year filed a patent for the Stereolithography Apparatus (SLA). Figure 1.1 displays the first SLA machine and printed part. Additive manufacturing, previously termed rapid prototyping, was officially started when 3D Systems introduced the first commercially available AM system, the SLA-1, in 1987. Various terms referred to additive manufacturing until 2009 when the ASTM F42 committee formed supported by SME's RTAM community. In 1993, researchers at the Massachusetts Institute of Technology (MIT) patented "three-dimensional printing techniques," which specifically referenced binder jetting (Sachs, Haggerty, Cima and Williams, 1993). The patent defined the process as:

> . . .making a component by depositing a first layer of a fluent porous material, such as a powder, in a confined region and then depositing a binder material to selected regions of the layer of powder material to produce a layer of bonded powder material at the selected regions. (US Patent US5204055A, Abstract)

Three-dimensional printing, abbreviated as "3DP" or "3D printing," has evolved and is now used to refer to inkjet-based, low-cost, hobbyist 3D printers. 3D printing is considered synonymous with additive manufacturing. In general, industry insiders use additive

Figure 1.1 First Stereolithography Machine and First 3D Printed Part
Source: Courtesy of 3D Systems, Inc.

manufacturing or AM, and the public typically uses 3D printing or 3DP to refer to the industry. For this book, both terms refer to the broad range of technologies and processes that comprise additive manufacturing.

Additive manufacturing and 3D printing (AM) technologies began to appear in the 1980s and have since become a significant force for revolutionizing product design, production process efficiency and effectiveness, supply chains, and innovation processes. According to Grand View Research (2020), the global AM market will exceed $35 billion by 2027. North America will likely maintain the largest market share of around 35%.

The primary business drivers for rapid growth and investment in AM continue to be enhanced product manufacturing and reduced time to market.

Continued growth and proliferation of AM are expected, with two key challenges that may hamper growth over the coming decade:

1. An overzealous focus on prototyping and low-volume production prevents organizations from realizing AM benefits at all phases of the manufacturing process.
2. Lack of a skilled workforce hampers the opportunities enabled by evolving technologies and processes.

Misguided Focus Prevents Realization of AM Benefits

AM was initially used in prototyping and to produce complex customized or low-volume production parts. These focused applications of AM led to the limited adoption of additive manufacturing technologies. For example, consider traditional injection molding, where a liquid polymer injects into a mold. When evaluated for use in injection molding, the AM focus tends to address increased part complexity, eliminate the mold, or incorporate conformal cooling, multimaterial or gradient-material usage, and speed. There is frequently a failure to consider the application and benefits in the other injection molding elements enabled by AM. In many circumstances, additive manufacturing is critical in providing elaborate fixtures, conformal cooling, mold inserts, and other support areas of the injection molding process. The aerospace and medical industries, which focused on prototyping in their initial AM application, provide another example. These industries realized significant cost savings and reduced lead-times by leveraging the technologies for design verification or presurgical models. However, other significant advantages exist for organizations that push past this initial narrow scope of AM applications.

The shift to AM requires considerable capital investment. For manufacturing firms to adopt these evolving technologies, key decision makers need to understand and leverage the broad range of benefits from more widespread use and application of AM technologies across the entire manufacturing process. Industries will only realize the value-add of AM through the work of a well-prepared and innovative workforce who can make it happen!

Lack of Skilled Workforce Limits Ability to Take Advantage of Opportunities

A skilled workforce is an essential component to exploit AM in any manufacturing and production setting fully. It is the existence of qualified employees who understand how to apply these technologies to current processes to improve and innovate. Research in over 400 manufacturing firms by Deloitte and The Manufacturing Institute revealed that the number of new manufacturing jobs would grow by almost 2 million workers by 2028 (Giffi et al. 2018). Furthermore, more than half of open positions in 2028 could go unfilled due to boomer retirements, misperceptions of manufacturing work, and new skillsets required to work with advanced manufacturing technologies.

In response to the well-publicized manufacturing skills gap and workforce shortages, various education and training initiatives in AM have developed. However, most of the efforts have attracted new generations of workers through high school, two-year trade and technical school, and four-year university programs. Current manufacturing practitioners rely on vendor-specific training, professional association workshops, on-the-job experimentation and training, and certification opportunities as venues for acquiring the necessary AM skills. Unfortunately, the efforts intended to address the manufacturing skills gap appear to have fallen short. A recent update to the Deloitte skills gap study indicated that workers' shortfall for available manufacturing jobs might be even higher than the original 2 million estimated (Wellener et al. 2020). A national desire to return the manufacturing of critical goods to the US following the COVID-19 pandemic may further exacerbate the manufacturing workforce shortage in the coming years.

This book prepares current manufacturing practitioners to move from traditional manufacturing practices to incorporating AM technologies and processes in their skillsets by providing a broad foundation for further learning. Existing additive manufacturing books and much available training for practitioners focus on the technical aspects of additive manufacturing and 3D printing technologies and techniques without assisting the practitioner in bridging the knowledge gap. This book's focus is to provide an end-to-end introduction covering all AM technologies and processes to allow the reader to develop a foundation for implementation in any manufacturing role while also broadening understanding of the scope of applications possible. Building a basic understanding of AM technologies and processes while providing broad coverage of potential applications will allow practitioners to more easily transition to the much-in-demand additive manufacturing workforce and leverage evolving technologies within their organizations.

Vital elements of additive manufacturing are introduced in upcoming chapters with enough technical details to provide the practitioner with a background to participate in the discussion of initiatives in their organizations and analyze the solutions presented. The remainder of this chapter covers an overview of manufacturing processes and examples of the unique applications facilitated by AM. A discussion of how traditional manufacturing job roles change in AM and suggestions for additional training and development follows. The end of the chapter provides a roadmap and recommendations for using the book.

AM Notable 1.1 - Are You Ready for Industry 4.0?

Industry 4.0, known as the new digital industrial revolution, integrates cloud computing, cognitive computing, the Internet of Things, and cyber-physical systems to automate and exchange data in manufacturing. This new industrial revolution enables unprecedented communication between products, means of production, and the humans involved. Software focused on traditional manufacturing limited AM's ability to reach its potential, but recent developments address AM's unique issues. HP and Dyndrite recently announced an advanced software solution to support end-to-end AM processes and management solutions. It also connects to popular third-party software tools used in manufacturing (HP's Universal Build Manager Powered by Dyndrite, 2020).

What does that mean for the manufacturing workforce? It means almost every manufacturing employee will need to understand and use advanced systems in their work, so better sharpen up those technical skills!

MANUFACTURING PROCESSES

Manufacturing processes comprise four broad process categories: formative, subtractive, additive, and hybrid, used to produce a part or finished product. Figure 1.2 illustrates these categories. A general description of each type appears below, and specific examples of manufacturing processes included in each category are listed and described in Table 1.1:

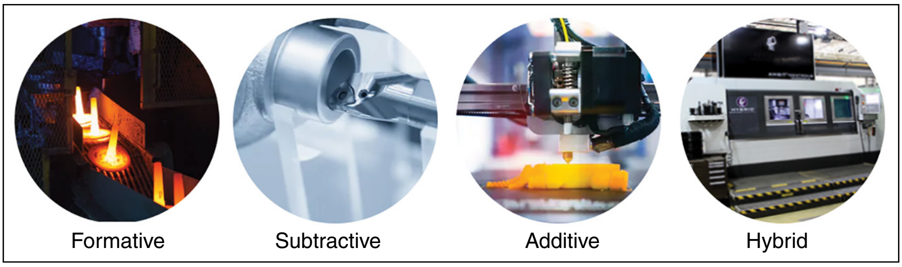

Figure 1.2 Types of Manufacturing Processes
Source: Shutterstock.com (Formative, Subtractive, Additive); Hybrid image courtesy of Concurrent Technologies Corporation.

Table 1.1 Manufacturing Processes

Formative
Casting is the process of pouring liquid material, typically heated from solids, into a mold cavity to create the desired shape. This process is mostly used for metals. Investment and sand-casting processes are commonly used for metals.
Forming is the process of creating a desired metal part ramming the metal into the desired shape using a hammer or die. The material can be heated or at room temperature, depending on the process.
Molding is the process of pouring liquid material, heated from solids, into a mold under pressure, to create the desired shape. Die casting is for metals and injection molding for plastics. Both processes inject the material under high pressure and produces parts with superior surface finishes.
Stamping is the process of using a die, with compressive forces, to create a desired shape from a sheet metal. The process uses different forming techniques to produce complex parts.
Subtractive
Computer Numerical Control (CNC) is the process of using computer programming to control a cutting tool in precise movements to achieve a desired shape.
Drilling is the process of using a rotary cutting tool to create a hole into an object. The cutting tool referred to a drill bit, spins at different speeds, depending on the material, to remove material by shearing and extrusion. The material can be made of metal, plastic, or wood.
Milling is the process of removing material from an object using a rotary cutting tool to the desired shape. The object can be cut from different angles and axes.
Turning is the process of removing material from an object as it rotates to create a cylindrical part. The cutting tool is pressed against the rotating object to remove material vis shearing.

Table 1.1 *(Continued)*

Additive	
	Binder jetting is the process of fusing powdered material with a binder using printheads. The material can be ceramic, plastic, or metal.
	Directed energy deposition is the process fusing metal filament or powder using a laser or electron beam as the powder is sprayed or the filament extruded. The process can fuse multiple powdered material at the same time or in sequence using multiple nozzles.
	Material extrusion is the process fusing metal or plastic material by heating and extruding the filament. Bonding occurs as the material cools down to a solid.
	Material jetting is the process fusing liquid material, typically thermosets, by spraying droplets of the material through a printhead.
	Powder bed fusion is the process of fusing metal or plastic powder using a laser or electron beam on a flat plate.
	Sheet lamination is the process of fusing layers of material and using a cutter or mill to achieve the desired shape.
	Vat photopolymerization is the process of fusing liquid material using an ultraviolet light, in form of a laser of projection, to create the desired from a vat.
Hybrid	
	Directed energy deposition + CNC is the process of fusing powdered metal using a laser within a CNC machine to build layers of the part whilst machining after a few layers to achieve the accuracy and surface finish of the subtractive process and higher complexity of the additive process.
	Powder bed fusion + Milling is process of fusing powdered metal using a laser on a bed of powder and machining the inside and outside surfaces every 10 layers. This process allows the creation of conformal cooling channels within a mold and deep cuts within the part, only possible with other machining processes like electrical discharging machine (EDM).
	Sheet lamination + CNC Milling is process of fusing thin metal foils using ultrasonic welding and machining the inside and outside surfaces every few layers. This process allows the creation of gradient material, including different metal combinations, internal cooling channels and capability to embed sensors and electronics within a part.

Source: Original, Kamara and Faggiani, 2020.

- *Formative.* Formative manufacturing processes include those that shape the material into the desired form and may use a mold or a die. Materials used may be melted, heated, or at room temperature, depending on the specific process. In general, formative techniques are used for high volumes of the same part and support lower part costs.
- *Subtractive.* Subtractive manufacturing processes remove material from a solid block or a near-net shape to achieve the desired size and geometry of the finished object. These techniques may use computer numerical control (CNC) machines, plasma torches, sheers, or other material-removal equipment. Parts or products produced by subtractive processes typically have simple geometry and are made in medium volumes.
- *Additive.* Additive manufacturing processes use computer-aided design (CAD) files to create ultra-thin digital slices of the desired shape, built-up by bonding layers of material together based on the slices to form an object. Additive manufacturing enables complex part geometry and typically produces parts in low to medium volumes.
- *Hybrid* Hybrid manufacturing processes achieve the desired shape of an object by combining either formative or subtractive processes with additive techniques sequentially within the same machine. This approach combines the complexity possible with additive methods and the superior finishing possible through other processes.

TRADITIONAL AND AM JOB ROLES

Manufacturing jobs generally include work in any process necessary to turn raw materials or components into new products. Broadly defined, classic manufacturing work falls into the following categories:

- *Process.* Work to select and implement the desired production process for parts or products; performed by a manufacturing engineer.
- *Design.* Work to conceptualize and design parts or products and optimize the design to leverage the selected process; performed by design engineers.
- *Material.* Work to identify and select the correct material for parts or products, particularly where the material must meet certain conditions; performed by material engineers.
- *Compliance.* Work to understand and ensure that parts or products meet ethical, safety, or regulatory standards; performed by a compliance engineer or compliance manager.
- *Testing.* Work to create a process or method to test and validate the part or product to ensure specifications are met; frequently performed by a test engineer or test analyst.

Various job titles exist within these general categories, and some roles may overlap among the types. Table 1.2 includes typical manufacturing job titles and brief descriptions from the US Bureau of Labor Statistics in the first two columns. The first column also shows new job titles for AM-specific roles emerging in job postings. Let's consider how traditional roles may need to evolve or be enhanced in additive manufacturing.

Table 1.2 How Additive Manufacturing Changes Job Roles

Role	Traditional Manufacturing	In Additive Manufacturing
Manufacturing Production Technicians **New Job Titles:** • Field Service Technician (AM)	Set up, test, and adjust manufacturing equipment.	• New technologies • New techniques (machine calibration, build preparation, part finishing, etc.) • New IT data and software skills
Manufacturing Engineers **New Job Titles:** • Additive Manufacturing Process Engineer	Design, integrate, or improve manufacturing systems or related processes.	• New technologies • More collaboration with commercial/design engineers • Rethink fabrication and modeling • Utilize DFAM (design for additive manufacturing) • New materials
Manufacturing Engineer Technologists **New Job Titles:** • Additive Manufacturing Technologist	Develop tools, implement designs, or integrate machinery, equipment, or computer technologies to ensure effective manufacturing processes.	• New technologies • Innovate with jigs/fixtures • More collaboration with manufacturing, manufacturing production technicians, and commercial/design engineers
Industrial Production Managers **New Job Titles:** • Senior Additive Manufacturing Engineer • Application Development Technical Service Manager (AM)	Plan, direct, or coordinate the work activities and resources necessary for manufacturing products in accordance with cost, quality, and quantity specifications.	• New technologies • Technical and management cross-functional competencies

(Continued)