

Preface

The exciting new field of 3D printing has captured the imagination of makers and artists envisioning Star Trek type replicators, organic free-form designs and the desktop fabrication of everything from food and toys to robots and drones. A natural extension of this desire is to capture thoughts and dreams using metal due to its strength, durability and permanence.

Today, 3D printing and the field of additive manufacturing (AM) have received a lot of attention due to the introduction of personal 3D printers for the home, multi-million dollar government funding of additive and advanced manufacturing programs and corporate investments in research and development centers. Wild enthusiasm has been created within some sectors of industry and finance and most importantly among young people, creating the possibility of a rewarding career in additive manufacturing. The best way to temper this enthusiasm without losing momentum is to offer a balanced view of where the technology is today and where it can be tomorrow. As makers, how do we prepare for this opportunity? As a business owner, how can this affect my bottom line or that of my competitors? How mature is the technology and what long-term strategic advantages might it hold? A discussion of AM accomplishments and challenges, without all the hype, is needed to instruct, motivate, and create a devoted group of followers, learners, and new leaders, to fuel the passion and create the future of this technology.

This book is an introductory guide and provides learning pathways to 3D metal printing (3DMP) of near net shaped, solid free-form objects. That is objects that require little finishing to use and do not rely on design constrained by the limitations of current fabrication methods. Additive manufacturing is a term that broadens the scope of 3D metal printing to include a wide range of processes that start with a 3D computer model, incorporate an additive fabrication process, and end up with a functional metal part. The distinction between 3DMP and AM processes is blurring due to the rapid evolution of the many competing methods used to make a 3D metal part. In this book we will use both 3DMP and AM references, with a preference to AM.

The book presents a comprehensive overview of the fundamental elements and processes used to “3D print” metal. The structure of the book provides a roadmap of

where to start, what to learn, how it all fits together, and how additive manufacturing can empower you to think beyond conventional metal processing to capture your ideas in metal. In addition, case studies, recent examples, and technology applications are provided to reveal current applications and future potential. This book shows how affordable access to 3D solid modeling software and high-quality 3D printing services can enable you to ascend the learning curve and explore how 3D metal printing can be put to work for you. This method of access enables us to begin our learning without the need to invest in the high-cost of professional engineering software or commercial additive manufacturing machines.

Those processes that sinter a bed of metal powder, fuse powder, or wire using high energy beams, or those hybrid processes that combine both additive and subtractive manufacturing (SM) methods may all fall under the category of AM. AM related processes have evolved at a dizzying pace spawning an avalanche of acronyms and terms, not to mention new companies being born, acquired and left behind.

In this book I will attempt to be internally consistent with the terminology and generic enough in their descriptions to minimize reliance on company names and trademarks. Rather than put a trademark symbol after every occurrence of a trademarked name, I will use names in an editorial fashion only and to the benefit of the trademark owner, with no intention of infringement of the trademark nor endorsement of the company. I admire the efforts of all these companies, past, present, and future and hope they succeed in these early days of technology development and adoption.

Together, we will look ahead and offer predictions of how 3DMP and AM will integrate into society and the global economy of a smaller, flatter world. We will combine our thoughts and dreams, amplified by advances in computing and information technology, to think of better ways to harness and transform metal into objects that serve us and help create an enduring future.

High-cost commercial additive manufacturing machines can range in price from hundreds of thousands of dollars to millions of dollars, but this does not mean we cannot begin to explore the technology without one. The price is sure to drop to levels affordable to small- and mid-size businesses, with metal printing services following suit. Hybrid versions of 3D plastic printing technology and low-cost versions of 3D weld deposition systems for the hobbyist are already in development. The current momentum of innovation in this rapidly changing field will provide affordable access to high quality 3D metal printers by the time we are ready to use them. In some cases we are already there. In this spirit, we proceed by adopting the analogy of you, the maker, as a *hitchhiker* and commercial 3D metal printers as the *vehicles* needed to manufacture your parts and solidify your dreams.

To achieve this goal, the book begins by providing the reader with a foundational understanding of how to learn and apply fused metal deposition to 3D printed parts. To understand keywords, phrases, technical terms, and concepts, you need to understand and speak the language of AM. These terms and jargon are listed and

defined, within the context of AM processing and are located in the Glossary at the end of this book.

It is hard to separate the hype from the fact using common Web searches to discern amateur from professional opinion. Web searches using Google Scholar¹ provide links to a rich body of technical papers and published works, and in some cases provide open access to technical publications. Peer-reviewed technical publications are available for purchase although persons new to the field often need to establish a broader foundation of knowledge to fully benefit from the latest reported research.

Industry reports such as the Wohlers Report,² considered by many to be the bible of 3D printing, present a yearly update to the latest developments within the technology but do not provide the technical detail of how these processes work. This book directs the readers to articles in online publications and magazines, covering the additive manufacturing industry, to provide in-depth coverage of technical advancements.

In this book we strive to provide cost effective references, search terms in italics, Web links and references to complement a consistent technical description of AM metal printing processes, allowing readers to engage in just-in-time learning as directed by knowledgeable and appropriate sources.

Additive manufacturing (AM) refers to a large and complex field encompassing model-based design engineering, computer-aided design (CAD) and computer-aided manufacturing (CAM) software, process engineering and control, materials science and engineering and industrial practice. To date, a comprehensive “how to” text on the AM processes of metals, more commonly referred to as 3D metal printing, is not yet available. Technical experts working in AM often have expertise in one or more of these fields but few have a deep understanding of the entire technical spectrum. Publications are spread across a very wide range of journals and Web based sources. The issue is, books specifically focused on “How to 3D print with metal” do not exist. This need for a single source of entry-level information provides another motivation for this book.

Those with a strong interest in additive manufacturing technology often do not know where to start to get a high-level structured view of the processes as applied to metals. This may be intimidating or confusing to beginners and those considering “dabbling” in or exploring the technology. You need not be a student, a maker, a metal fabricator, or a business owner to see the potential in AM or have an interest in how to 3D print metal. AM is complex enough that those embarking on the path of “experiential self-learning” are often stymied by lack of preparation or basic knowledge needed to succeed in those first few projects required to assess the

¹Google Scholar provides access to a wide range of technical papers, citations and patents. <http://scholar.google.com/>, Setting Google or Google Scholar alerts is a good way to stay up to date on the latest developments of the technology and market place.

²Wohlers, T., & Caffrey, T. (2014), Wohlers Report 2014—3D Printing and Additive Manufacturing State of the Industry, Wohlers Associates, <http://www.wohlersassociates.com/>, (accessed March 30, 2015).

technology and gain confidence. Most books on “How to 3Dprint” are popular books on 3D printing plastics, some are overhyped or strictly forward-looking. Additive manufacturing textbooks often attempt to cover the entire spectrum of materials and sacrificing important design considerations, process details, or application considerations as applied to metal. “How to” books on AM are good start, but if your interest is in metals you should find a book that focuses on these AM materials.

Vendor-supplied operation manuals or Web links to recommend “standard conditions” exist for specific materials using a specific system, but the truth is most owners and users of high end commercial systems are also engaged in trial and error development, otherwise known as learning the hard way. Vendor-supplied guidelines are either very generic or strictly prescriptive, imparting a recipe but without an in-depth understanding of why we do what we do. Vendors often protect standard operating parameters as proprietary, keeping them secret from the machine owners, also obscuring the workings of the technology. Much has been written in the technical literature regarding *how to* 3D print metals, but more often than not there is little mention of how *not to* 3D print with metals, or the information is presented as a partial work leaving out relevant details. Knowing what can go wrong is often just as important as knowing how to get it right.

What is 3D metal printing and how does it differ from 3D printing with plastics or other materials? How can I create complex metal objects and move beyond the constraints of conventional metal processing? How can I learn the basics, explore and choose the 3D metal printing process that is right for me? In this book you will learn you do not need a degree in engineering, or a million dollar 3D metal printer, to reach the cutting-edge of additive manufacturing.

An additional goal of this book is to help you decide what you need to get started, what types of software, materials, and processes are right for you, what additional knowledge is required, and where to get it. For those just starting out or those embarking on a new career path, AM holds promise to be a good profession, offering a rewarding, well-paying career from the production floor, to the corporate research and development (R&D) lab, to a viable commercial business opportunity. Emerging careers in additive and advanced manufacturing are hot real estate and if you have the will, there is surely a way. If this book inspires you to take either path, we have succeeded twice, as some of this book will be sure to remain with you on your journey.

I begin by emphasizing the fundamental understanding of 3D metal printing, identifying the building blocks, why we do what we do, and what is important to you the maker. The book provides information often overlooked related to critical applications, such as those in aerospace, automotive, or medical fields and the rigorous path to certification. The average maker may never build a rocket ship or reach for the stars or design and build a unique medical device that saves lives, but you never know. This book will introduce the reader these topics and applications.

3D additive manufacturing moves us toward a more complex and information-rich environment. We are not just creating the “soul of a new machine,” we are creating its DNA as well. This product DNA information generated and stored along the way will include a cradle-to-grave documentary of design, fabrication, and service life. Not only do we create the DNA, we grow the object and put it to work.

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