Preface

Additive manufacturing (AM), interchangeably referred to as 3D printing, has never received so much attention. Considering all of the recent spotlights in the mainstream media, one might think that AM is a new breakthrough in the advanced manufacturing industry. However, our institution, Nanjing University of Aeronautics and Astronautics (NUAA) has been working with this technology since the mid-1990s. The designations of this technology have also changed from the initial “rapid prototyping (RP)” to the present “additive manufacturing (AM)” which is regarded as a more general designation that reflects directly the unique processing philosophy of this advanced manufacturing technology. Depending on the material and objective of the final application, there are various AM processes that have been commercially available. The most common materials presently applied for AM are typically plastics, metals, and alloys such as Al-based, Ni-based, Ti-based, and Fe-based alloys. Meanwhile, more novel materials with unique properties are currently being investigated for AM and are likely to be used successfully in the near future. The most popular AM processing systems for metallic components typically use a laser to heat, melt, and consolidate powder materials. Laser-based AM technology for the fabrication of metallic components typically has two basic categories according to the different mechanisms of laser-powder interaction. One is based on the laser powder bed approach (i.e., prespreading of powder on powder bed before laser melting) and the typical processes include direct metal laser sintering (DMLS) and selective laser melting (SLM); the other is based on the laser powder feeding method (i.e., coaxial feeding of powder by nozzle with synchronous laser melting) and the typical process is laser metal deposition (LMD) or laser engineered net shaping (LENS). DMLS/SLM and LMD represent two different development directions for AM of metallic components. Parts produced by DMLS/SLM are impressive in their elaborate structures including the thin walls, sound surface finish, fine features, and small internal channels, due to the small focused laser beam size and thin powder layer thickness (generally less than 100 μm) applied during the DMLS/SLM process. Contrarily, LMD has a versatile process capability and can be applied to manufacture new components, to repair and rebuild worn or damaged components, and to prepare wear and corrosion resistant coatings. LMD demonstrates a high capability in producing the larger-sized 3D parts, since the deposition layer thickness during LMD is in the order of millimeters. It is noted that the high deposition rate of LMD process, which is regarded as a process base for producing large components, inevitably results in the decrease in the dimensional precision of the final components after layer-by-layer deposition. LMD is accordingly a "near net shaping" AM process for the large 3D components, as relative to the "net shaping" capability of DMLS/SLM process for the relatively small 3D components.

Laser-based AM technology, due to its unconventional material incremental manufacturing philosophy combined with the highly non-equilibrium metallurgical nature of the laser process, provides a beneficial method to simultaneously develop new materials, complex 3D configurations, and unique microstructures and properties. This book describes the capabilities and characteristics of the development of new metallic material components by laser-based AM process, including nanostructured material, *in situ* composite material, particle reinforced metal matrix composites, etc. The topics and results presented in this book, similar to the laser AM technology itself, show a significant interdisciplinary feature, integrating laser technology, materials science, metallurgical engineering, and mechanical engineering. The book comprehensively covers the specific aspects of laser-based AM of new material components, in terms of materials design and preparation, process control and optimization, and theories of physical and chemical metallurgy. As a major idea highlighted in the book, the integration of "Designed Material", "Tailored Process" and "Controllable Property" presents one of the most important strategies for future sustainable research and development in laser-based AM of high-performance metallic components. We may understand the laser-based AM technology from various aspects such as process control, material design, apparatus and software, microstructure and property evaluation, etc. This book chooses a unique angle to view the research and development progress of laser-based AM technology. An interesting and important issue in AM research fields, i.e., the development of high-performance new material components by laser-based AM process, is emphasized in this book. The combination of the tailored laser-based AM process with the new materials hopefully leads to some interesting outcome, e.g., the simultaneous realization of complex shapes, unique microstructures, and high performance. We believe it is a unique book for researchers, students, practicing engineers, and manufacturing industry professionals interested in laser-based AM and laser processing of powder materials.

The book is divided into ten chapters and a quick preview of the contents is given as follows:

Chapter 1 introduces the development history of AM technology and the nomenclature principles for naming different types of AM processes. The general processing philosophy and the typical applications of AM technology are presented.

Chapter 2 reviews the current status of research and development in the three most versatile laser-based AM processes for metallic components, including laser sintering (LS), laser melting (LM), and laser metal deposition (LMD). The ever-reported metallic powder materials used for AM are classified and the associated bonding and densification mechanisms during laser-based AM are proposed. An in-depth review of the materials aspects of laser-based AM processes is presented, including physical aspects of materials for AM, microstructural/mechanical properties of AM-processed parts, and structure/property stability of AM-fabricated parts, in order to establish the relationship between material, process, and metallurgical mechanism of various laser-based AM processes.

Chapter 3 presents the selective laser melting (SLM) AM processing of nanocrystalline TiC reinforced Ti matrix bulk-form nanocomposites. The controlled crystallization and development mechanisms of nanostructures of TiC reinforcement in SLM-processed Ti-based nanocomposites are disclosed and the underlying role of microstructural development in mechanical properties of SLM-processed nanocomposites is elucidated.

Chapter 4 presents the SLM fabrication of the *in situ* Ti–Si intermetallic-based TiC/Ti_5Si_3 and TiN/Ti_5Si_3 composite parts with novel reinforcement architecture and elevated mechanical performance. The underlying material–process–microstructure–property relationship is established to enable the successful laser-based AM of the designed *in situ* composites.

Chapter 5 proves the feasibility of the SLM process in producing the high melting point *in situ* WC cemented carbide based hardmetals. The SLM AM process demonstrates to be a unique method to produce the WC-based hardmetals parts with novel microstructural characteristics and mechanical properties.

Chapter 6 presents the SLM processing of the nanoscale TiC particle reinforced AlSi10Mg nanocomposite parts. The microstructural evolution of nanoscale reinforcement in SLM-processed parts at different SLM processing parameters is studied and the attendant densification level and mechanical properties are assessed, in order to enable the successful production of Al-based composites with nanoscale reinforcement architecture and elevated mechanical performance.

Chapter 7 deals with the SLM production of novel Al-based composites with multiple reinforcing phases starting from the SiC/AlSi10Mg composite powder having an *in situ* reaction nature. The present research attempt reveals the promising potential of SLM process in producing novel lightweight composites with unique reinforcing structures and performance.

Chapter 8 reports on the direct metal laser sintering (DMLS) AM processing of the WC particle reinforced Cu matrix composite parts. A novel design method of the graded interface between the WC reinforcing particles and the Cu matrix is applied and the formation mechanism of the graded interfacial structure during DMLS process is proposed. The control and optimization mechanisms of processing conditions and materials combinations are proposed to improve the microstructural homogeneity and resultant mechanical performance of DMLS-processed WC/Cu composites.

Chapter 9 presents the DMLS consolidation of the nano/micron W–Cu composites, which is a unique materials system due to the mutual insolubility of W and Cu. The effects of the DMLS processing parameters and the Cu-liquid content in the system on the densification behavior and microstructural characteristics of DMLS-processed W–Cu composites are disclosed. A novel W-rim/Cu-core structure and its formation mechanism during DMLS are proposed, which is regarded as a unique laser induced metallurgical phenomenon of this insoluble system.

Chapter 10 summarizes the main findings and contributions of this monograph, along with some important issues and suggestions for future sustainable development of laser-based AM technology.

This book serves as a systemic sum-up of my research work during the past 12 years on laser-based AM of high-performance new metallic materials components. As you may see, the laser-based AM research work on these materials has been carried out using the laser powder bed approach including selective laser melting (SLM) and direct metal laser sintering (DMLS). Nevertheless, the basic conclusions as presented in this book are applicable and/or transferrable to other laser-based AM processes, e.g., laser metal deposition (LMD) or laser engineered net shaping (LENS), as well as the laser-based powder processing techniques, e.g., laser cladding, laser surface alloying, laser melt injection, etc.

I gratefully appreciate your interest and the time taken to read this book entitled "Laser Additive Manufacturing of High-Performance Materials" and hope that you think it is a worthwhile work to add some unique understanding to this rapidly developing technology.

Nanjing, 2014
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