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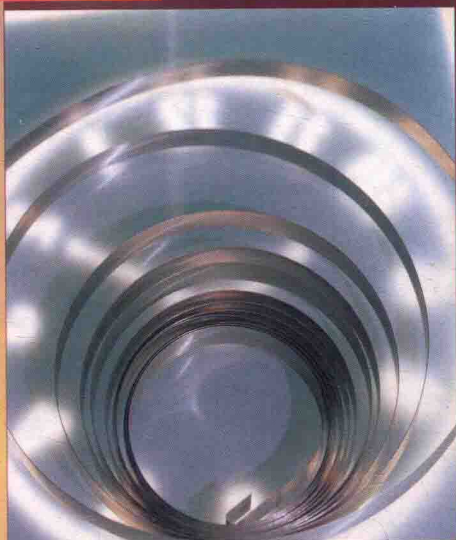

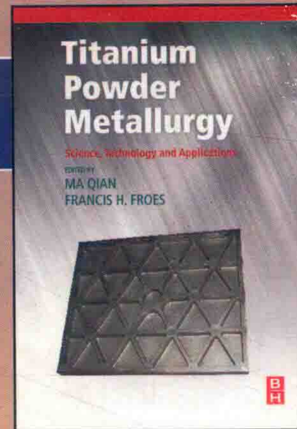

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Francis H. Froes 编著

钛粉末冶金：科学、技术及应用

Titanium Powder Metallurgy: Science, Technology and Applications

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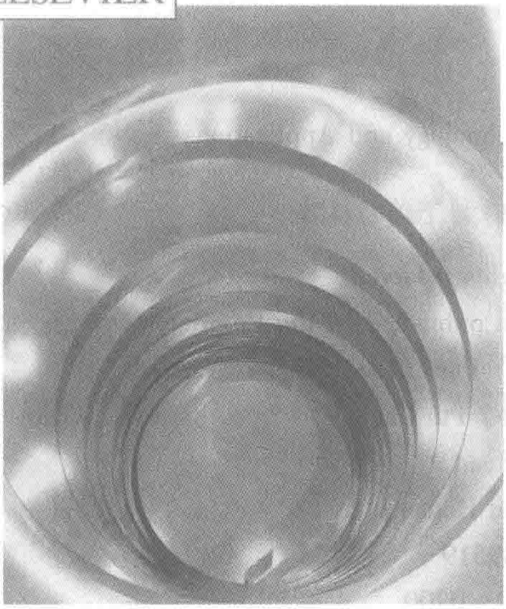

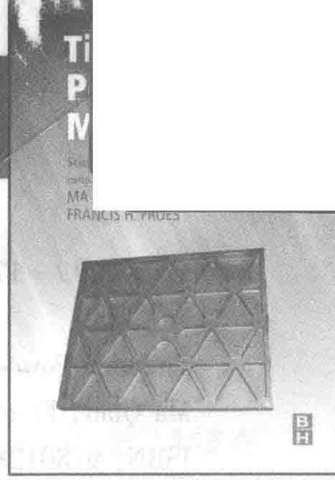

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内容简介

本书涵盖了钛粉末冶金领域最全面、最权威的内容，主要介绍钛粉末的生产、加工及工业应用和未来发展趋势，论证了粉末冶金可以为工业应用提供近净成型或净形成型的高性价比钛金属、钛合金及钛金属基复合材料的原因。本书适用于从事钛及钛合金粉末冶金研究的工程师和研究人员、钛粉和零件生产商、冶金和轻合金专业研究生使用。

作者简介

Ma Qian 澳大利亚皇家墨尔本理工大学增材制造中心教授兼副主任。发表论文 200 多篇，其中约一半是关于钛粉末冶金(PM)和钛合金的增材制造。

Francis H. Froes 博士，美国爱达荷大学教授。从事钛粉末冶金研究 40 多年。发表论文 800 篇，申请专利 60 项，主编约 30 种图书。曾任 ASM 研究员和俄罗斯科学院院士。

序

W. Kroll 博士发表在 *Z Metallkunde* 期刊(29(1937)189 - 192)的文章，是已知最早的关于钛粉末冶金的研究。在该论文中，Kroll 博士在氩气中压制并烧结了 14 种二元钛合金(Ti - Mo, W, Ni, Fe, Co, Be, Si, Mn, Cr, Cu, Al, Zr, V, Ta，添加元素质量分数为 2%~9%)。这是在他能够生产 0.5 kg 级海绵钛细粉后不久完成的。1937 年以来，Kroll 工艺持续发展(1937 年末 Kroll 博士从钙法转向镁法)，1948 年，Dupont 公司首次生产出高质量的海绵钛(3 t，纯度 >99%)，首届钛研讨会在华盛顿召开，确立了钛在美国作为一种金属的工业地位。尽管时间已过去 70 年，但与成本较低的钢铁和铝合金结构材料相比，钛部件的高成本仍然限制了其应用。钛部件的高成本主要与锻造制品机械加工最终形状有关，这启发人们制备近净成型钛产品，大幅度增加其应用。就这一点而言，粉末冶金技术仍然是生产低成本近净成型钛部件的有效方法。此外，粉末冶金技术可以快速生产样件，不用模具制备复杂零件，以及修复加工失误和磨损零件。粉末冶金的另一个重要优势是可以生产铸锭冶金由于偏析问题而不能生产的合金。

本书回顾钛粉末冶金技术的发展，介绍钛粉的生产方法(包括成熟的和正在发展的有潜力的低成本方法)、近净成型粉末冶金技术(包括元素粉末法、预合金化 + 热压法、增材制造法、金属注射成型法和喷涂成型法)。最后两章讨论钛粉末冶金技术的当前市场和潜在市场，提出编者的未来展望。总之，本书全面覆盖了钛粉末冶金技术领域，作者期待以此实现粉末冶金钛部件在未来的广泛应用。

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Dr. Ma Qian is Professor and Deputy Director of the Centre for Additive Manufacturing of RMIT University (Royal Melbourne Institute of Technology), Australia. He received his BSc (1984), MSc (1987), and PhD (1991) all from the University of Science and Technology Beijing. He then worked as a postdoctoral research fellow and lecturer with Tsinghua University Beijing from 1991 to 1994. Before joining RMIT University in 2013, he was a Reader in Materials Engineering (2008–2013) and leader of the Powder Metallurgy Group at the University of Queensland, Australia. Prior to that, he worked as a researcher or academic with several other institutions in Japan, Singapore, Australia, and the United Kingdom. He has more than 200 peer-reviewed publications, with about half focused on titanium powder metallurgy (PM) and additive manufacturing of titanium alloys. Recent publications include understanding the effect of oxygen on the ductility of as-sintered Ti-6Al-4V (*Acta Mater.* 68 (2014) 196–206), Additive manufacturing of strong and ductile Ti-6Al-4V (*Acta Mater.* 85 (2015) 74–84) and understanding the impacts of trace carbon on the microstructure of as-sintered biomedical Ti-15Mo (*Acta Biomater.* 10 (2014) 1014–1023). He initiated the Titanium PM conference in 2011, cosponsored by Materials Australia, the Minerals, Metals & Materials Society (TMS), Japan Society of Powder and Powder Metallurgy (JSPM), Titanium Industry Development Association (TiDA), and the PM Branch of China Society for Metals (CSM). He was leader organizer for the TMS Symposium Novel Synthesis and Consolidation of Powder Materials (2013 and 2015). Currently he serves as a board member of the Asian Powder Metallurgy Association (APMA) and an editorial/review/advisory board member of a number of journals including *Metallurgical and Materials Transactions A*, *JOM*, *Powder Metallurgy*, *International Journal of Powder Metallurgy*, *Korean Journal of Powder Metallurgy*, *Acta Metallurgica Sinica (English Letters)*, and *Powder Metallurgy Technology*. He is also advisory editor to Elsevier on powder materials science and engineering.

Dr. Francis H. (Sam) Froes has been involved in the Titanium field with emphasis on powder metallurgy (PM) for more than 40 years. After receiving a BSc (Liverpool University) and an MSc and PhD (from Sheffield University) he was employed by a primary titanium producer, Crucible Steel Company, where he was leader of the titanium group and led a major effort on PM titanium under US Air Force (USAF) funding. He then spent time at the USAF Materials Lab, where he was supervisor of the Light Metals group (which included titanium) and again involved an emphasis on PM. While at the USAF Laboratory, he coorganized a landmark TMS-sponsored Conference on Titanium PM (1980) and presented the keynote speech at the first International Titanium Association Conference in 1984. This was followed by 17 years at the University of Idaho, where he was a director and department head of the

Materials Science and Engineering Department, again leading a number of programs on titanium PM. During this tenure, he was the Chairman of the World Titanium Conference held in San Diego in 1992. He has more than 800 publications, in excess of 60 patents, and has edited almost 30 books – the majority on various aspects of titanium. Recent publications include a comprehensive review of titanium PM and an article on titanium additive manufacturing. Since the early 1980s, he has taught the ASM International course on "Titanium and Its Alloys." He has organized more than 10 symposia on various aspects of Titanium Science and Technology, including in recent years cosponsored four TMS Symposia on Cost Effective Titanium (which included a large number of papers on titanium PM). He is a Fellow of ASM and a member of the Russian Academy of Science, and he was awarded the Service to Powder Metallurgy by the Metal Powder Association.

Preface

The first known research effort of titanium powder metallurgy (PM) was made by Dr Kroll (W. Kroll, Verformbare Legierungen des Titans, *Z Metallkunde*, 29 (1937) 189–192). In the work published, Dr Kroll compacted and sintered 14 different binary titanium alloys (Mo, W, Ni, Fe, Co, Be, Si, Mn, Cr, Cu, Al, Zr, V, and Ta with one addition for each element in the range of 2–9 wt%) in argon soon after he was able to produce about 0.5 kg batches of sponge fines in 1937. Thanks to the persistent development of the Kroll process since 1937 (Dr Kroll switched to the magnesium approach from the calcium in late 1937), titanium as a metal of industrial stature was established in 1948 in the United States, marked by world's first high-quality sponge production by DuPont (3 metric tons of >99% pure sponge in 1948) and the 1st Titanium Symposium in Washington, DC, held also in 1948. Although more than seven decades have passed, the high cost of titanium components still limits its usage compared to the lower-cost structural material options such as steel and aluminum alloys. A major proportion of this high cost is associated with the machining of wrought products to final configurations, suggesting that fabrication of near-net shaped titanium products could lead to dramatically increased use. In that regard, PM techniques remain to be an attractive solution to the production of cost-effective near-net shaped titanium components. In addition, it offers the potential for rapid turnaround prototype parts, manufacture of complex parts without having to make dies or molds, and a method for repairing mismachined parts or worn parts. Another important advantage is that Powder Metallurgy (PM) offers the potential of producing alloys that could not be produced via ingot metallurgy due to segregation problems.

The purpose of this book is to review the developments of titanium PM technologies to date. The subjects covered include titanium powder production methods, including both well-established and developing potential lower-cost approaches, and various near-net-shape-forming PM techniques, including the blended elemental approach, the prealloyed plus hot isostatic pressing method, additive manufacturing, metal injection molding, and spray forming. The last two chapters discuss the current and future markets for Ti PM and the editors' perspectives on the future of Ti PM. In total, the field has been covered in a comprehensive manner and we hope that this effort could help in bringing titanium components made from powder into widespread use in the future.

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