

Titanium Powder Metallurgy

Science, Technology and Applications

EDITED BY

MA QIAN

FRANCIS H. FROES



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Ma Qian

**RMIT University, School of Aerospace,
Mechanical and Manufacturing Engineering,
Centre for Additive Manufacture, Melbourne,
Victoria, Australia**

Francis H. (Sam) Froes

**Consultant to the Titanium Industry, Tacoma,
WA, USA**



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List of contributors

Stanley Abkowitz Dynamet Technology, Inc. (now RTI Advanced Powder Materials a unit of RTI International)

Susan Abkowitz Dynamet Technology, Inc. (now RTI Advanced Powder Materials a unit of RTI International)

Kamal Akhtar Director of Technology and Quality, Cristal Metals Inc., Lockport, IL, USA

Kerem Araci Process Development Engineer, Technology and Quality, Cristal Metals Inc., Lockport, IL, USA

Daniel P. Barbis AMETEK Specialty Metal Powders

Christopher C. Berndt Industrial Research Institute Swinburne, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, Australia; Department of Materials Science and Engineering, Stony Brook University, NY, USA

R.R. Boyer Retired Boeing Technical Fellow, Seattle, WA, USA

G.M.D. Cantin CSIRO Process Science and Engineering, Clayton South MDC, Victoria, Australia

Joseph A. Capone AMETEK Specialty Metal Powders

Richard R. Chromik Department of Mining and Materials Engineering, McGill University, Montréal, Québec, Canada

L.P. Clark Retired Boeing, Phoenix, AZ, USA

Melchiorre Conti Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

James Deane Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

Greg Doughty Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

B. Dutta DM3D Technology, Auburn Hills, MI, USA

Z. Zak Fang Department of Metallurgical Engineering, University of Utah, Salt Lake City, UT, USA

Thomas Ebel Helmholtz-Zentrum Geesthacht, Zentrum für Material- und Küstenforschung GmbH, Geesthacht, Germany

Sami M. El-Soudani Associate Technical Fellow, The Boeing Company, Huntington Beach, CA, USA

Harvey Fisher Dynamet Technology, Inc. (now RTI Advanced Powder Materials a unit of RTI International)

V. Friederici Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM, Bremen, Germany

Francis H. (Sam) Froes Consultant to the Titanium Industry, Tacoma, WA, USA

Jo Ann Gan Industrial Research Institute Swinburne, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, Australia; Research Services, La Trobe University, Melbourne, Australia

Robert M. Gasior AMETEK Specialty Metal Powders

Randall M. German Professor, Mechanical Engineering, San Diego State University, San Diego, CA, USA

M.A. Gibson CSIRO Process Science and Engineering, Clayton South MDC, Victoria, Australia

Dina Goldbaum Department of Mining and Materials Engineering, McGill University, Montréal, Québec, Canada

Lucy Grainger Metalysis Limited, Wath-upon-Dearne, Rotherham, United Kingdom

T. Hartwig Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM, Bremen, Germany

M. Ashraf Imam Materials Science and Technology Division, Naval Research Laboratory, Washington DC, USA

P. Imgrund Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM, Bremen, Germany

Eric Irissou National Research Council Canada, Boucherville, Québec, Canada

Orest Ivasishin Institute for Metal Physics, Kiev, Ukraine

Mingtu Jia Waikato Centre for Advanced Materials, School of Engineering, The University of Waikato, Hamilton, New Zealand

Katsuyoshi Kondoh Osaka University, Joining and Welding Research Institute (JWRI), Ibaragi, Osaka, Japan

Jean-Gabriel Legoux National Research Council Canada, Boucherville, Québec, Canada

Bin Liu State Key Lab of Powder Metallurgy, Central South University, Changsha, P.R. China

Yong Liu State Key Lab of Powder Metallurgy, Central South University, Changsha, P.R. China

Shudong D. Luo The University of Queensland, School of Mechanical and Mining Engineering, Brisbane, Australia

Damien Mangabhai Quality Superintendent, Technology and Quality, Cristal Metals Inc., Ottawa, IL, USA

Ian Mellor Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

Vladimir Moxson ADMA Products, Inc., Hudson, OH, USA

James D. Paramore Department of Metallurgical Engineering, University of Utah, Salt Lake City, UT, USA

Ma Qian RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering, Centre for Additive Manufacture, Melbourne, Victoria, Australia

Kartik Rao Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

V. Samarov President, LNT PM Inc. (Laboratory of New Technologies)

Teddi S. Schaeffer AMETEK Specialty Metal Powders

D. Seliverstov President, LNT PM Inc. (Laboratory of New Technologies)

Pei Sun Department of Metallurgical Engineering, University of Utah, Salt Lake City, UT, USA

H.P. Tang State Key Laboratory of Porous Metal Materials, Northwest Institute for Nonferrous Metal Research, Xi'an, China

David S. van Vuuren The CSIR, PO Box 395, Pretoria, South Africa

Dion Vaughan Metalysis Limited, Wath-upon-Deane, Rotherham, United Kingdom

Phuong Vo National Research Council Canada, Boucherville, Québec, Canada

Graham P. Walker AMETEK Specialty Metal Powders

J. Wang State Key Laboratory of Porous Metal Materials, Northwest Institute for Nonferrous Metal Research, Xi'an, China

David Whittaker DW Associates 231, Coalway Road, Merryhill Wolverhampton, United Kingdom

J.C. Williams Professor Emeritus, The Ohio State University, Columbus, OH, USA

James C. Withers Materials & Electrochemical Research (MER) Corporation, Tucson, AZ, USA

Wilson Wong Department of Mining and Materials Engineering, McGill University, Montréal, Québec, Canada

X. Wu ARC Centre for Design in Light Metals, Monash University, Melbourne, Australia

Ming Yan RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering, Centre for Additive Manufacture, Melbourne, Victoria, Australia

Ya F. Yang RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering, Centre for Additive Manufacturing, Melbourne, Victoria, Australia

C.F. Yolton CTO, Summit Materials LLC, McDonald, PA, USA

Stephen Yue Department of Mining and Materials Engineering, McGill University, Montréal, Québec, Canada

Deliang Zhang State Key Laboratory of Metal Matrix Composites, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai, China

About the editors

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.

Ma Qian

RMIT University, School of Aerospace, Mechanical and Manufacturing
Engineering, Centre for Additive Manufacture, Melbourne, Victoria, Australia

Francis H. (Sam) Froes
Consultant to the Titanium Industry, Tacoma, WA, USA

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