

**Advances in the Science and Engineering of**  
**CASTING SOLIDIFICATION**

An MPMD Symposium Honoring Doru Michael Stefanescu

**EDITORS**

Laurentiu Nastac, Baicheng Liu, Hasse Fredriksson,  
Jacques Lacaze, Chun-Pyo Hong, Adrian V. Catalina,  
Andreas Buhrig-Polaczek, Charles Monroe, Adrian S. Sabau,  
Roxana Elena Ligia Ruxanda, Alan Luo, Subhayu Sen, and  
Attila Diószegi

**TMS**

 **Springer**

**Advances in the Science and Engineering of**  
**CASTING SOLIDIFICATION**

An MPMD Symposium Honoring Doru Michael Stefanescu

# TMS2015

**144<sup>th</sup> Annual Meeting & Exhibition**

**March 15-19, 2015 • Walt Disney World • Orlando, Florida, USA**

---



# **Advances in the Science and Engineering of CASTING SOLIDIFICATION**

An MPMD Symposium Honoring Doru Michael Stefanescu

*Proceedings of a symposium sponsored by*  
the Materials Processing & Manufacturing Division of  
The Minerals, Metals & Materials Society (TMS)

*held during*

**TMS2015**  
144<sup>th</sup> Annual Meeting & Exhibition

March 15-19, 2015

Walt Disney World • Orlando, Florida, USA

## **EDITORS**

Laurentiu Nastac, Baicheng Liu, Hasse Fredriksson,  
Jacques Lacaze, Chun-Pyo Hong, Adrian V. Catalina,  
Andreas Buhrig-Polaczek, Charles Monroe, Adrian S. Sabau,  
Roxana Elena Ligia Ruxanda, Alan Luo, Subhayu Sen, and  
Attila Diószegi

*Editors*

Laurentiu Nastac

Baicheng Liu

Hasse Fredriksson

Jacques Lacaze

Chun-Pyo Hong

Adrian V. Catalina

Andreas Buhrig-Polaczek

Charles Monroe

Adrian S. Sabau

Roxana Elena Ligia Ruxanda

Alan Luo

Subhayu Sen

Attila Diószegi

ISBN 978-3-319-48605-5

ISBN 978-3-319-48117-3 (eBook)

DOI 10.1007/978-3-319-48117-3

Chemistry and Materials Science: Professional

Copyright © 2016 by The Minerals, Metals & Materials Society

Published by Springer International Publishers, Switzerland, 2016

Reprint of the original edition published by John Wiley & Sons, Inc., 2015, 978-1-119-08238-5

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer International Publishing AG

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# TABLE OF CONTENTS

## Advances in the Science and Engineering of Casting Solidification

Preface .....	xi
About the Honoree.....	xiii
About the Editors .....	xv

### **Solidification Processing I**

Science of Casting and Solidification: ASM Handbook Contributions – Honoring Professor Doru Michael Stefanescu .....	3
<i>A. Lupulescu, S. Henry, K. Marken, and S. Lampman</i>	
On the Solidification of Metal Alloys during Microgravity Conditions .....	9
<i>H. Fredriksson</i>	
Formation of the Tin Rich Layer and Inverse-Segregation in Phosphor Bronzes during Continuous Casting .....	15
<i>S. Saleem, M. Vynnycky, and H. Fredriksson</i>	
A Model of Cavitation for the Treatment of a Moving Liquid Metal Volume .....	23
<i>G. Lebon, K. Pericleous, I. Tzanakis, and D. Eskin</i>	
Ultrasonic Processing of 6061-Based Nanocomposites for High Performance Applications .....	31
<i>S. Jia, P. Allison, T. Rushing, and L. Nastac</i>	
Numerical Modeling of the Dispersion of Ceramic Nanoparticles during Ultrasonic Processing of A356-based Nanocomposites .....	37
<i>D. Zhang and L. Nastac</i>	
Optical Floating-Zone Crystal Growth of Heusler Ni-Mn-Sn Alloy .....	49
<i>J. Yu, J. Ren, H. Li, and H. Zheng</i>	

### **Solidification Processing II**

Modeling of Macrosegregation during Solidification of Steel Ingot Casting ....	57
<i>W. Tu, H. Shen, and B. Liu</i>	

Scaling Analysis of Alloy Solidification and Fluid Flow in a Rectangular Cavity .....	65
<i>A. Plotkowski, K. Fezi, and M. Krane</i>	
Structure and Casting Defects of Aluminum Billets Produced by Direct-Chill Casting .....	73
<i>D. Eskin</i>	
The Fluid Flow and Solidification Phenomenon in Billet Continuous Casting Process with Mold and Final Electromagnetic Stirrings .....	81
<i>D. Jiang and M. Zhu</i>	
Columnar-to-Equiaxed Transition in Zn-27wt.%Al Alloys: A Comparison Between Vertical and Horizontal Directional Solidifications .....	93
<i>A. Ares and C. Schvezov</i>	
Microstructure Investigation of Aluminum Die-Cast Parts with Different Gating Conditions Tested in Fatigue .....	101
<i>R. Ruxanda and R. Obara</i>	

### **Solidification Processing III**

A Coupled Thermo-Mechanical Simulation on Squeeze Casting Solidification Process of Three-Dimensional Geometrically Complex Components .....	113
<i>J. Tang, Z. Han, F. Wang, J. Sun, and S. Xu</i>	
Double Oxide Film Defects in Al Castings and the Effect of Different Element Additions .....	121
<i>Q. Chen, A. Caden, and W. Griffiths</i>	
The Design of New Submerged Entry Nozzles for Beam-Blank Continuous Casting .....	129
<i>M. Zhu, M. Xu, and S. Luo</i>	
Effects of Ce on the Thermal Stability of the $\Omega$ Phase in a Cast Aluminum Metal Matrix Composite .....	137
<i>F. Melotti, A. Dustan, T. Hirst, and W. Griffiths</i>	

## **Solidification Processing IV**

Non-Metallic Ti Oxides and MnS/FeS <sub>2</sub> Complex Precipitation in Ti-Killed Steel .....	147
<i>J. Chen, D. Zhao, H. Li, and S. Zheng</i>	
Prediction of Surface Porosity Defects in High Pressure Die Casting .....	155
<i>M. Saeedipour, S. Schneiderbauer, S. Pirker, and S. Bozorgi</i>	
Engineered Cooling Process for High Strength Ductile Iron Castings .....	165
<i>S. Lekakh, A. Mikhailov, and J. Kramer</i>	
Numerical Simulation of Solidification Structure for YQ450NQR1 Steel Bloom in Continuous Casting Process .....	173
<i>K. Dou, L. Wang, J. Qing, X. Zhang, B. Wang, B. Liu, and Q. Liu</i>	

## **Microstructure Evolution I**

Modeling of Microstructure Evolution during Alloy Solidification .....	183
<i>M. Zhu, S. Pan, and D. Sun</i>	
A Lattice Boltzmann Model for Dendritic Growth under Natural Convection .....	191
<i>M. Hashemi, M. Eshraghi, and S. Felicelli</i>	
Modeling of Dendritic Structure and Microsegregation in Solidification of Al-Rich Quaternary Alloys .....	199
<i>T. Dai, M. Zhu, S. Chen, and W. Cao</i>	

## **Microstructure Evolution II**

In Situ Study on the Evolution of Dendrite Morphology Affected by Electric Field in Sn-Bi Alloy .....	209
<i>F. Yang, F. Cao, R. Li, H. Kang, Y. Fu, T. Xiao, and T. Wang</i>	
Heterogeneous Strip Originated from Inclusions: Characterization and Physical Mechanism .....	215
<i>X. Ma and D. Li</i>	
An Investigation of Dendritic Segregation in Directionally Solidified CMSX-4 Superalloy .....	223
<i>G. Matache, D. Stefanescu, C. Puscasu, and E. Alexandrescu</i>	



Modeling of Casting Defects in an Integrated Computational Materials Engineering Approach .....	231
<i>A. Sabau</i>	

X-ray Observations Showing the Effect of Fluid Flow on Dendritic Solidification in Ga-In Alloys.....	241
<i>N. Shevchenko, O. Roshchupkina, and S. Eckert</i>	

## **Cast Iron I**

Defect Formation Mechanisms in Lamellar Cast Iron Related to the Casting Geometry .....	251
<i>A. Diószegi, P. Svidró, L. Elmquist, and I. Dugic</i>	

Characterization of Directionally Solidified Gray Iron .....	261
<i>E. Rivera, T. Christiansen, A. Genau, and A. Catalina</i>	

Age-Strengthening of Cast Iron and Its Effects on Machinability: Review of the Literature .....	269
<i>V. Richards</i>	

Examination of Austenite Solidification and Spheroidal Graphite Growth in Ni-Fe-C Alloys .....	277
<i>J. Qing, V. Richards, and D. Van Aken</i>	

Production of Selected Key Ductile Iron Castings Used in Large-Scale Windmills .....	287
<i>Y. Pan, H. Lin, C. Lin, and R. Chang</i>	

An Overview of Isothermal Coarsening in Hypoeutectic Lamellar Cast Iron .....	295
<i>J. Hernando and A. Diószegi</i>	

## **Cast Iron II**

Experimental Studies of Gray Cast Iron Solidification with Linear Variable Differential Transformer .....	305
<i>A. Tadesse and H. Fredriksson</i>	

Undercooling, Cooling Curves and Nodule Count for Hypo- Hyper- and Eutectic Thin-Walled Ductile Iron Castings .....	313
<i>W. Kapturkiewicz and A. Burbelko</i>	

Graphite Growth Morphologies in High Al Cast Iron .....	323
<i>H. Muhmond and H. Fredriksson</i>	
Thermophysical Properties of Thin Walled Compacted Graphite Iron Castings .....	331
<i>M. Górný, J. Lelito, and M. Kawalec</i>	
Understanding Cast Iron Materials and Components: A Never Ending Story .....	339
<i>I. Svensson and J. Olofsson</i>	
Understanding Superfine Graphite Iron Solidification through Interrupted Solidification Experiments .....	347
<i>G. Alonso, D. Stefanescu, P. Larrañaga, E. De la Fuente, E. Aguado, and R. Suarez</i>	

## **Novel Casting and Molding Processes**

Counter Gravity Casting .....	357
<i>J. Campbell</i>	
A Numerical Model for Predicting the Gas Evolution in Silica Sand (Furan Binder) Mold Castings .....	363
<i>L. Nastac, S. Jia, M. Nastac, and R. Wood</i>	

## **Solidification Processing V**

Evaluation of the Casting/Chill Interface Thermal Behaviour during A319 Alloy Sand Casting Process .....	373
<i>F. Mehr, S. Cockcroft, C. Reilly, and D. Maijer</i>	
Dependence of Hardness on Microstructure of a Directionally Solidified Sn-40wt.%Bi-0.7wt.%Cu Alloy .....	381
<i>B. Silva and J. Spinelli</i>	
Contributions on Optimizing Approximations in the Study of Melting and Solidification Processes that Occur in Processing by Electro-Erosion .....	391
<i>F. Potra, T. Potra, and V. Soporan</i>	

Investigation of Thin-Walled IN718 Castings by Counter-Gravity Investment Casting .....399  
*A. Dong, N. Yan, J. Zhang, J. Wang, B. Sun, H. Gao, and D. Shu*

Thermal Test of Nodular Cast Iron Cooling Stave .....407  
*J. Zheng, H. Zuo, J. Zhang, and F. Li*

Author Index .....413

Subject Index .....415

## PREFACE

This book contains the proceedings of the honorary symposium, “Advances in the Science and Engineering of Casting Solidification, held at the TMS 2015 Annual Meeting & Exhibition in Orlando, Florida, March 15-19, 2015. The symposium was held in honor of Professor Doru Michael Stefanescu, emeritus professor of The Ohio State University and The University of Alabama at Tuscaloosa, USA.

This book encompasses the following four areas:

- (1) *Solidification Processing*: theoretical and experimental investigations of solidification processes including castings solidification, directional solidification of alloys, electromagnetic stirring, ultrasonic cavitation, mechanical vibration, active cooling and heating, powder bed-electron beam melting additive manufacturing, etc. for processing of metals, polymers and composite materials.
- (2) *Microstructure Evolution*: theoretical and experimental studies related to microstructure evolution of materials including prediction of solidification-related defects and particle pushing/engulfment aspects.
- (3) *Novel Casting and Molding Processes*: modeling and experimental aspects including high pressure die casting, permanent casting, centrifugal casting, low pressure casting, 3D silica sand mold printing, etc.
- (4) *Cast Iron*: all aspects related to cast iron characterization, computational and analytical modeling, and processing.

The topics included in this volume were selected to reflect the broad research interests of Prof. Stefanescu. The participants in this symposium are leading scientists in the field of casting and solidification from around the world. A significant number of the participants were also either his students or colleagues.

This book advances the state-of-the art science and engineering of casting solidification and microstructure evolution of materials. Also, it introduces to the audience advanced characterization and multiscale modeling and simulation techniques as well as related novel processing methods.

Finally, this symposium has been organized to recognize the important contributions of Prof. Stefanescu to our community as a leading scholar in the casting and solidification field, a mentor, an advisor, and a great friend. We would like to thank Doru for being a role model for all of us.

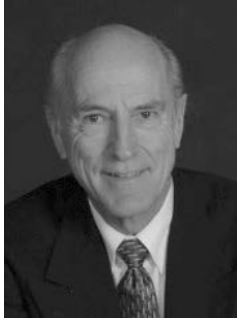
On behalf of all symposium organizers and participants,

**Prof. Laurentiu Nastac**

The University of Alabama

Dept. of Metallurgical & Materials Engineering

## ABOUT THE HONOREE



Professor Doru Michael Stefanescu's scientific career spans more than four decades. He graduated with a Dipl. Eng. degree in Metallurgical Engineering from the University Politehnica Bucharest, Romania in 1965 and obtained a Ph.D. in Physical Metallurgy from the same institution in 1973. In 1980 he served as a Visiting Professor at the University of Wisconsin, Madison and then joined The University of Alabama where he taught and did research until 2005 when he retired as Cudworth Professor of Engineering Emeritus. He continued his scholarly activity as Ashland Designated Research Professor at The Ohio State University until 2010. During his activity at these universities Professor Stefanescu has conducted 39 Master of Science theses and 17 Philosophy Doctor dissertations. He has authored or co-authored 393 publications.

The third edition of his book *Science and Engineering of Casting Solidification* will be published by Springer in 2015. He is a Doctor Honoris Causa of the Technical University of Cluj-Napoca, Romania (1998); the University Transylvania, Brasov, Romania (2001); and Jonkoping University, Sweden (2012).

Prof. Stefanescu's research interests include experimental and numerical aspects of solidification processing, influence of low-gravity on solidification, processing of metal-matrix composites, processing of ceramic superconductors, manufacturing technologies and physical metallurgy of cast iron, steel and nonferrous alloys, and cast metals technology. He is recognized as a world expert in cast iron.

Professor Stefanescu was the Key Foundry Educational Foundation faculty at The University of Alabama between 1982 and 2005, and then served in the same position at The Ohio State University between 2005 and 2010. On November 5, 1999 the Foundry Educational Foundation in cooperation with the American Foundry Society presented him with the AFS Director's Award to recognize his efforts as an educator.

The University of Alabama has recognized Dr. Stefanescu's achievements by honoring him with the three most prestigious awards that it confers to deserving faculty: the Burlington Northern Foundation Faculty Achievement Award (1988), the Burnum

Distinguished Faculty Award (1990), and the Blackmon-Moody Outstanding Professor Award (1997). He is also the recipient of the 2009 Lumley Research Award, College of Engineering, The Ohio State University.

Dr. Stefanescu honors and awards include Fellow of the ASM International (1997) “*For fundamental contributions to the science of solidification through the modeling of solidification processes and the microstructural evolution of castings*”, the Award for Scientific Merit of the American Foundry Society (2000) for “*research involving cast iron solidification modeling, inoculation and cooling curve analysis as well as work with aluminum alloys and cast metal matrix composites*”, the Joseph Seaman Gold Medal of the American Foundry Society (2011), Honorary Member of the Romanian Academy of Technical Sciences (2012), and the John Campbell Medal from the Institute of Cast Metals Engineers, United Kingdom (2012). He was also awarded four NASA Certificates of Recognition for the Creative Development of Technical Innovations.

## EDITORS



### **Laurentiu Nastac**

Laurentiu Nastac is currently an Associate Professor of Metallurgical and Materials Engineering at The University of Alabama, Metallurgical and Materials Engineering Department, Tuscaloosa, Alabama. He is also the Key Foundry Educational Foundation (FEF) Professor and the Director of the Solidification and Ultrasonic Laboratories and of the MTE foundry. Dr. Nastac received the Diploma Engineering degree in Metallurgy and Materials Science from the University Politehnica of Bucharest, Romania in 1985 and the M.S. and Ph.D. degrees in Metallurgical and Materials Engineering from The University of Alabama (Advisor, Prof. Doru M. Stefanescu), Tuscaloosa in 1993 and 1995, respectively. He has held various engineering, research, and academic positions in Romania (1985-1991) and the United States (1991-present). At Caterpillar (1994-1996), he conducted research in the area of macro transport and solidification-kinetics modeling and developed specialized casting simulation software tools. At Concurrent Technologies Corporation (CTC; 1996-2011) he conducted research primarily in the area of advanced metal-casting and solidification processes with emphasis on the modeling and simulation of casting phenomena. In 1999, in recognition of his work on solidification of Ti-based alloys and superalloy remelt ingots, he received the prestigious “Bunshah Best Paper Award” from the American Vacuum Society, Vacuum Metallurgy Division. More recently, he received the NMC (Navy Metalworking Center) achievement award and two CTC awards.

Dr. Nastac developed eight software tools, made over 150 presentations, co-authored three patents and over 195 publications in the materials science and manufacturing fields, and co-authored eight books, one of which is a monograph titled *Modeling and Simulation of Microstructure Evolution in Solidifying Alloys* published by Springer in 2004. He is a Key Reader for *Metallurgical and Materials Transactions*, a member of the Editorial Board of the *International Journal of Cast Metals Research* and of the ISRN Materials Science, and a member of the TMS Solidification Committee. He served in scientific committees

and as an organizer for international conferences dedicated to casting and solidification processes and CFD modeling and simulation in materials processing.



### **Baicheng Liu**

Baicheng Liu graduated with Gold Medal Award from Tsinghua University in 1955. As a visiting scholar, he studied at University of Wisconsin-Madison and Massachusetts Institute of Technology from 1978 to 1981. He is now a professor in the School of Materials Science and Engineering and School of Mechanical Engineering of Tsinghua University. He was elected as an academician of the Chinese Academy of Engineering in 1999. He won “Guanghua Engineering Science and Technology Prize” in 2002 and “Outstanding Contribution for Casting Industry” by the Chinese Mechanical Engineering Society in 2012.

His major research interests are multiscale modeling and simulation of solidification process of shape casting, physical metallurgy of cast alloys and strategy study of development of advanced manufacturing industry as well. He won a number of first and second class awards of scientific and technological achievements from Ministry of Education and Ministry of Machinery Industry and also two awards from the United States.

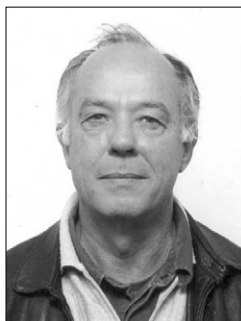
He has published more than 300 papers. He was invited to visit and give presentation to 30 more universities of different countries, and present more than 30 papers including several keynote speeches in different international conferences.



### **Hasse Fredriksson**

Hasse Fredriksson has been a professor in Casting of Metals at KTH since 1975 and is responsible for the research and education in the field of casting and solidification of metals at KTH. He has been the supervisor to 40 doctoral theses and to more than 50 master’s theses. Prof. Fredriksson is the author or co-author of more than 250 scientific publications in the field of solidification and casting and has organized and edited seven international conferences. He is coauthor of the following books: *Materials Processing during Casting*, *Physics of Functional Materials*, and *Solidification Processing of Metals*, all published by John Wiley & Sons.





### **Jacques Lacaze**

After engineering studies in Nantes (west coast of France), Jacques Lacaze prepared a Ph.D. thesis (1979-1982) in Paris dealing with solidification of continuous cast aluminum alloys in relation with their hot tearing tendency. Dr. Lacaze then got a position as associate researcher at the Centre National de la Recherche Scientifique (CNRS) and moved to Nancy where he stayed until 1994. That year he moved to Toulouse where he matured as a senior scientist at CNRS.

His work in Nancy was mainly concerned with microscopic aspects of solidification of metallic alloys, including aluminum alloys, steels, and nickel-base superalloys. This research was carried out within a team, headed by Gérard Lesoult, and was concerned with multiscale studies of solidification, from microscopic to macroscopic aspects. Focus was mainly put on designing original experiments, but the possibility of resorting to modelling was always considered.

In 1985-1986, Dr. Lacaze took a one year post-doctoral position in the Royal Institute of Technology in Stockholm (KTH) where he started works on cast irons (with Prof. Hasse Fredriksson) and thermodynamic optimization and calculations (with Bo Sundman). Back to Nancy, he became involved in most of the research performed in the team, including several projects on solidification of cast irons. These latter projects were mainly dealing with nodular cast irons in relation with the tube manufacturer Pont-à-Mousson. In the early 1990s, he was asked by this manufacturer to extend his investigations to the solid-state eutectoid transformation of nodular cast irons.

Moving to Toulouse, he joined a so-called transversal team dealing with mechanics, microstructure, oxidation, and corrosion which now includes 14 permanent staff, 12 permanent researchers and professors, one technician, and one research engineer. Within this team, Dr. Lacaze has brought his knowledge about heterogeneous phase transformations, including solidification and solid-state transformation of metallic alloys. Most of the studies there deal with structural alloys that have to undergo severe service conditions, including mechanical loading, high

temperatures, and aggressive environments (oxidation) for energy and transport.

Studying cast irons has remained his preferred research area, and half of the 50 papers he has co-authored in recent years are concerned with these alloys. These papers deal with solidification, solid-state transformation and mechanical properties of nodular irons, though most of the principles put forward would apply to other types of cast irons. His main present interest is on the role of impurities.



### **Chun-Pyo Hong**

Chun-Pyo Hong graduated from Yonsei University, Korea in 1972, received a M.S. degree in Materials Processing from Tohoku University, Japan in 1975, and received a Ph.D. degree in Materials Science and Engineering from University of Tokyo, Japan in 1985. From 1975 to 1985, he taught at Kyung Pook National University, Korea. Since 1986, he has taught at the Department of Materials Science and Metallurgy at Yonsei University, Seoul, Korea. During this period, he has published more than 150 journal papers, 50 conference papers, and published about 30 patents. He has also published several textbooks, including *Computer Modelling of Heat and Fluid Flow in Materials Processing* from IOP in 2004. One of his invented techniques, named “nano-cast” which is a new rheo-diecasting method, is being commercially used for the production automobile cast parts in Japan and Korea.



### **Adrian V. Catalina**

Adrian V. Catalina received his bachelor's degree in Metallurgical Engineering from the University Politehnica of Bucharest (Romania) in 1985. He worked as a foundry engineer (ICM Resita), research engineer (ICSITPSCM Bucharest), and lecturer (University Politehnica of Bucharest) before joining the Graduate School at the The University of Alabama from which he obtained his Ph.D. degree in Metallurgical and Materials Engineering. In 1999, Dr. Catalina joined the Microgravity Materials Science program at USRA/NASA Marshall Space Flight Center in Huntsville, Alabama and since 2004 he is a Senior R&D Engineer with the Virtual Product Development Division at Caterpillar. Among Dr. Catalina's research interests are

modeling of microstructure evolution during solidification processes and solid-state transformations of metallic alloys, prediction of defects formation in cast alloys, processing–microstructure–properties relationships, and development of high strength lightweight alloys are the most prominent. Dr. Catalina has published more than 20 journal articles, 25 conference papers, and has four patent applications.



**Andreas Buehrig-Polaczek**

Anderas Buehrig-Polaczek is head of the Foundry-Institute at RWTH-Aachen University, Germany. He received his Diploma (1987) and Doctorate of Engineering (Dr.-Ing.; 1992) in metallurgical engineering from the RWTH Aachen University, Germany. From 1998 to 2002 he was full professor at the Foundry Institute, University of Leoben, Austria, and General Manager of the Austrian Foundry Research Institute, Leoben, Austria. Since 2002 he has also served as Chairman of the Supervisory Board, ACCESS e.V. Materials & Processes, Aachen, Germany.

Prof. Buehrig-Polaczek is working in the fields of metallurgy, alloy and process development, solidification, simulation of casting processes, bionic and biomaterials, MMC's and metallic foams. He has more than 150 publications, and he likes to work in interdisciplinary teams in order to bring different aspects together. In cooperation with universities, he builds a national network for the faculties in materials science and engineering. Knowledge transfer and a close collaboration with the industry is a further aspect of his research activities. Prof. Buehrig-Polaczek is also member in several national and international boards of foundry related organizations, companies and journals, such as *International Journal of Cast Metals Research*.



### **Charles Monroe**

Charles Monroe is an Assistant Professor at the The University of Alabama at Birmingham (UAB). He received his B.S. in Mechanical Engineering from Pennsylvania State University in 2003 and his M.S. and Ph.D in Mechanical Engineering from University of Iowa in 2005 and 2008 respectively. Dr. Monroe grew up learning about steel castings from his father, Raymond, who actively supports research in this area through the trade association, Steel Founders' Society of America. After his education, Dr. Monroe spent several years working for Caterpillar running analysis of all types of metal castings and processes. Here he developed many interests in research including hot tearing, thin wall filling, microstructure property relationships, cost analysis of casting manufacture, and more. At UAB, Dr. Monroe is the Key Professor in the Foundry Education Foundation and teaches classes to undergraduates and graduate students focusing on metal casting processing.



### **Adrian S. Sabau**

Adrian S. Sabau received his Diploma of Inginer in Mechanical Engineering/Materials Processing from the University of Craiova, Romania in 1992 and a Ph.D. degree in Mechanical Engineering from Southern Methodist University in 1996. In 1999, Dr. Sabau joined Oak Ridge National Laboratory as a Research Staff Member of the Materials Science and Technology, where he has been a Senior Research Staff Member since 2008. He is the recipient of two R&D 100 awards in process sciences. Dr. Sabau seeks to advance the materials processing, metal casting, photonic processing, and materials for energy applications through the development of solution algorithms, computational and experimental methodologies for the property measurement, process analysis, and materials behavior in response to conditions experienced in service, such as oxide exfoliation in steam boiler tubes and high-heat flux of tungsten-based materials for fusion applications. Dr. Sabau has published more than 50 journal papers, 73 conference papers, and has three patent applications.



### **Roxana Elena Ligia Ruxanda**

Roxana Elena Ligia Ruxanda received her Diploma Engineer in Casting and Solidification and Ph.D. degree in Thermal and Thermochemical Treatment of Alloys from the University Politehnica of Bucharest, Romania. In 1998, Dr. Ruxanda joined Dr. Stefanescu's group at the The University of Alabama as a post-doc NSF-NATO grant recipient and later as Research Assistant. In 2003, Dr. Ruxanda joined Emerson Climate Technologies in Sidney, Ohio, where currently occupies the position of Senior Lead Research Engineer in the Research Department. Dr. Ruxanda seeks to advance the materials characterization of metallic alloys, composite materials, polymers, solid residues, as well as the practical aspects of failure analysis and fractography, through metallography, image analysis, optical and electron microscopy, X-Ray fluorescence and diffraction, NDT ultrasonic, resonance acoustic methods, and X-Ray imaging. Dr. Ruxanda co-authored five chapters in ASM Handbook Volume 9 – Metallography and Microstructures, co-edited the proceedings of the *International Conference on the Science of Casting and Solidificatio* , published more than 70 refereed publications (journals and conference proceedings) and has two patent applications.



### **Alan Luo**

Alan Luo is Professor of Materials Science and Engineering and Professor of Integrated Systems Engineering (Manufacturing) at The Ohio State University (OSU) in Columbus, Ohio, USA. Dr. Luo is also Director of OSU Light Metals and Manufacturing Research Laboratory (LMMRL). Prior to joining OSU in July 2013, Dr. Luo was a GM Technical Fellow at General Motors Global Research and Development Center (Warren, Michigan, USA) with 20 years of industrial experience.

Dr. Luo won two John M. Campbell Awards for his fundamental research, and three Charles L. McCuen Awards for research applications at GM. He has 17 patents and more than 180 technical publications in advanced materials, manufacturing and applications. Dr. Luo is an elected Fellow of ASM International and the Society for Automotive Engineers International (SAE). He received the TMS (The Minerals, Metals & Materials Society)

Brimacombe Medalist Award, SAE Forest R. McFarland Award in 2013, USCAR (United States Council for Automotive Research) Special Recognition Award in 2009, and ASM Materials Science Research Silver Medal in 2008. Dr. Luo's research is also recognized by several Best Paper awards from TMS, SAE, and AFS (American Foundry Society). He is the vice chair of TMS Light Metals Division and SAE Materials Engineering Activity.



**Subhayu Sen**

Subhayu Sen is currently serving as a Principal Engineer and Subject Matter Expert for Geocent, LLC in support of Boeing's Space Launch System. Dr. Sen received his Bachelor of Technology in Metallurgical Engineering from the Indian Institute of Technology, Kharagpur, India and his M.S. and Ph.D. in Metallurgical and Materials Engineering from the The University of Alabama, Tuscaloosa (Advisor, Prof. Doru M. Stefanescu). He has held various engineering and research positions between 1995 to present. He was the lead materials engineer for NASA, Marshall Space Flight Center, Materials and Processes (2004–2012) directly supporting material and process selection, testing, and qualification for first stage Solid Rocket Boosters, Launch Abort System, and previous Space Shuttle components. In addition, he was the lead metallurgist for technology development program on net shaped aluminum component development for cryogenic tanks, working in close collaboration with NASA and European partners. Between 1995 and 2003 Dr. Sen served as the Principal Scientist and Flight Project Scientist for Space Shuttle and International Space Station Payloads. He was directly responsible for ensuring the scientific integrity of the flight projects and providing the science and engineering liaison between the NASA project team and the principal investigator. He was also the principal experimentalist for glovebox space flight experiment on metal matrix composite solidification performed on USMP-4 shuttle mission. Dr. Sen has been the recipient of several NASA and Space Flight awards in recognition of his achievements in the field of aerospace materials. He has presented numerous invited scientific papers at international conferences and has over 50 publications in referred journals.



### **Attila Diószegi**

Attila Diószegi became an engineer in material science at Technical University of Cluj in Rumania, 1984. The work carrier started up with employments as foundry technician at Rumanian foundries: IOB Bals and IAIFO Zalau. The foundry carrier was continued in Sweden 1986 as a foundry worker at Traryds Metallgjuteri and as a foundry trainee at Scandinavian Foundry School in Jönköping. Between 1990 and 2005, Dr. Diószegi was employed at Volvo's Foundry in Skövde as pattern designer, casting simulation engineer, research engineer for development of cast materials and processes.

A Ph.D. degree was earned in 2004 from Linköping University on the subject of microstructure formation and mechanical properties in grey cast iron. The scientific carrier was started 2005 as assistant professor in component technology at Jönköping University (JU). Further scientific merits were obtained 2008 as associate professor in foundry technology at Jönköping University and 2010 as associate professor in applied foundry technology at the Royal Institute of Technology, Stockholm. Since 2011, Dr. Diószegi has been a visiting professor at the Institute of Material Science at University of Miskolc, Hungary. He was appointed professor of foundry technology at Jönköping University in March 2013.

The research area of foundry technology practiced by Dr. Diószegi is interdisciplinary. The research includes all cast alloys with focus on cast iron produced in both sand and permanent molds. Liquid metallurgy, mold filling, molding materials, nucleation, solidification, microstructure and defect formation, modelling and simulation are covered.

**Advances in the Science and Engineering of**  
**CASTING SOLIDIFICATION**

An MPMD Symposium Honoring Doru Michael Stefanescu

**Solidification**  
**Processing I**

**Session Chair:**  
Adrian S. Sabau



## **SCIENCE OF CASTING AND SOLIDIFICATION: ASM HANDBOOK CONTRIBUTIONS – HONORING PROFESSOR DORU MICHAEL STEFANESCU**

<sup>1</sup>Afina Lupulescu, <sup>1</sup>Scott Henry, <sup>1</sup>Karen Marken, <sup>1</sup>Steven Lampman

<sup>1</sup>ASM International  
9639 Kinsman Road, Materials Park, Ohio, 44073-002 USA

Keywords: Casting, Solidification, Computer Modeling, Microstructures

### **Abstract**

Many of the metal casting processes are still empirical in nature. Many others are deeply rooted in mathematics and therefore, suitable for modeling. Science of casting and solidification is a major technical asset for foundry operations and of extreme importance in understanding different length scales microstructural changes and evolution as well as developing new processes and materials. In his attempt to describe combinations of solidification theory, research results and industrial practice, Professor Doru Michael Stefanescu (*ASM Fellow, 1997*) has made tremendous contributions to the field. Many of his views on casting and solidification are valued as important impacts within professional environments such as TMS and ASM International. He has written many articles for the *ASM Handbook* series on subjects including basic metallurgy of cast iron, compacted graphite irons, solidification, thermodynamic properties of iron-base alloys, and computational modeling. He was also Volume Chair for Volume 15: *Casting*, of the 9<sup>th</sup> Edition *Metals Handbook*.

### **Introduction**

One of our authors first met Professor Doru Stefanescu in 1996, at *NASA*, Huntsville, Alabama while taking mission specific training for the space shuttle experiments that were soon to fly onboard space shuttle *Columbia*. At that point, Professor Doru Stefanescu was the Principal Investigator for the “Particle Engulfment and Pushing by Solidifying Interfaces” project while at University of Alabama, in Tuscaloosa. Since then, we had many professional group-to-group interactions and sharing common subjects during different professional meetings. Professor Doru Stefanescu’s vast knowledge and experience in casting and solidification has been a valuable touchstone in all of our interactions. Without being exhaustive, this non-conventional paper focuses on some of Professor Doru Stefanescu professional highlights with emphasis on his *ASM Handbook* contributions.

### **Professional Highlights**

Professor Doru Stefanescu had an interesting and complex professional journey starting with Polytechnic Institute in Bucharest, Romania. He is known for major accomplishments in casting

and solidification while at University of Alabama. When he got closer to retirement, he transitioned to Ohio State University where he continued his work. His prestigious industrial positions, numerous professional services and editorial review boards of international archival journals are completing his professional profile. Professor Doru Stefanescu's professional activity has been centered on the science of casting and solidification. *Science and Engineering of Casting Solidification* [1], as the title of his textbook highlights, covers the essentials of solidification science of metals and alloys at different length scales and cooling rates specific to commercial castings and rapid solidification processes. He and his group contributed to outlining mathematical fundamentals necessary to build a working knowledge in the field, specifically partial differential equations and numerical analysis. His professional achievements resulted in 380 publications including 35 invited papers, 32 books and chapters in books, 73 refereed journal publications, 63 AFS Transactions papers, 73 refereed conference publications, 24 other conference proceedings publications, 68 other technical publications, and 12 patents. By applying his pedagogical and mentoring talent, Professor Doru Stefanescu directed and produced 39 Master students, 17 Ph. D students, and 25 Postdoctoral fellows. Professor John Morral mentioned that under Professor Stefanescu's supervision, while at Ohio State, "the students interested in solidification and foundry had much enthusiasm and were active going to the FEF National meetings in Chicago and participated when AFS had National meetings in Columbus." Professor Morral also thinks that Professor Stefanescu "graduate program involved only a few students, although he won a number of awards during that time and was actively attending meetings and writing papers [2]." The numerous awards that Professor Stefanescu received add to his professional activity and international recognition. The *John Campbell Medal* - Institute of Cast Metals Engineers, United Kingdom, 2012, the *ASSOFOND plaque* - The Italian Foundry Federation, 2012, Honorary Member of the Romanian Academy of Technical Sciences, 2012, the *Joseph Seaman Gold Medal* of the American Foundry Society (2011), the 3 *Dr. Honoris Causa* titles (Technical University of Cluj-Napoca – Romania, 1998, University of Transylvania – Romania, 2001, Jonkoping University - Sweden, 2012), the *ASM Fellow*, 1997, and the four *NASA* certificates of recognition for creative development of a technical innovation, are just a few of the very prestigious awards and honors that he has received [Figure 1].



Figure 1. Professor Doru Stefanescu receiving the Dr. Honoris Causa award, at University of Transylvania, Romania, 2001.

Professor Stefanescu and our ASM group interacted during many professional events from which the *Science of Casting and Solidification* (SOCAS) meeting organized by him and his group, TMS annual events, and ASM contributions are the highlights. He has been invited to many conferences and meetings, and he has organized numerous Symposia.

## ASM Contributions

Many of his views on casting and solidification are valued as important impacts within professional environments such as TMS and ASM International. The time and dedication to perform each job is tremendous and highly appreciated by any professional society. Following his desire to disseminate worldwide the science of casting and metallurgy, Professor Doru Stefanescu has written many articles for the *ASM Handbook* series including articles about basic metallurgy of cast iron, compacted graphite irons, solidification, thermodynamic properties of iron-base alloys, solidification microstructures of aluminum and titanium alloys, as well as computational modeling. He also served as the Volume Chair for *Metals Handbook*, 9<sup>th</sup> Edition, Volume 15: *Casting*.

### Classification and Basic Metallurgy of Cast Iron

This topic is one of the subjects covered by Professor Doru Stefanescu in the *first Volume* of the *ASM Handbooks* [3, 4]. Castings are major manufacturing processes and are used in 90% of all manufactured goods. Therefore, the subject of castings is vast and understanding of its basic metallurgy and logistics is a top priority. Proper consideration of the end results of the Fe-C phase diagram, and establishing criteria for classifying the cast iron it is not a trivial job.

**Cast Iron** identifies a large family of multicomponent ferrous alloys involving an eutectic. Cast irons have a higher carbon and silicon contents than steel, and therefore exhibit a rich carbon phase (>2% C). Depending primarily on composition, cooling rate, and melt treatment, cast iron can solidify according to the thermodynamically metastable Fe-Fe<sub>3</sub>C carbide system or the stable Fe-Graphite system. Usually, the alloying elements may considerably change the maximum solubility of carbon in austenite ( $\gamma$ ). Therefore, in exceptional cases, alloys with less than 2% C can solidify with a eutectic structure and still belong to the family of cast iron. The formation of stable or metastable eutectic is a function of many factors including the nucleation potential of the liquid, chemical composition, and cooling rate. The first two factors determine the graphitization potential of the iron. A high graphitization potential will result in irons with graphite, while a low graphitization potential will result in irons with iron carbide. Classification criteria for cast irons are established by fracture (white and gray iron), graphite shape, microstructure of the matrix (ferritic, pearlitic, austenitic, martensitic, bainitic or austempered, or any combination of these phases), commercial designation (common and special cast iron), and mechanical properties (as listed by various national and international specifications). Professor Stefanescu discusses 5 classes of cast irons (gray, ductile, compacted, malleable, and special) outlining carefully the differences among them in terms of microstructure, chemical compositions as well as cooling rates, liquid, and heat treatment effects.

### Fundamentals of Solidification, Metallography and Microstructures for Steels and Cast Irons, Aluminum Alloys, Titanium Alloys; Computer Modeling of Solidification Microstructures

**Solidification** is the transformation of liquid matter into solid matter. Solidification of pure metals or alloys is one of the oldest manufacturing processes, for either cast or wrought as well as it is prone to modelling. This subject is presented by Professor Doru Stefanescu in *Volume 9* of the *ASM Handbooks* [5, 6, 7, 8, 9]. Solidification science initially evolved from the need of better understanding and developing casting processes. It further advanced to the science of many new developments that depart from traditional metal casting. The microstructure that results from solidification may be the final one, in which case it directly affects the mechanical

properties of the product. In many cases, heat treatment or other processes may be used after solidification to further modify the initial microstructure. Usually, it results into a specific microstructure and needed properties applicable to a specific part. The effect of solidification on the morphology of the matrix can be deciphered at different length scales: a) *the macroscale* ( $10^3$ -1m) describes shrinkage cavity, macrosegregation, cracks, surface roughness and casting dimensions; b) *the mesoscale* ( $10^4$ m) shows mechanical properties that are affected by the solidification structure, and dependent upon grain size and type (columnar or equiaxed), chemical microsegregation, microshrinkage, porosity, and inclusions; c) *the microscale* ( $10^6$ - $10^5$ m) describes the complex morphology of the grains during solidification. To evaluate the influence of solidification on the properties of the castings, it is necessary to know the as-cast grain morphology (i.e., size and type, columnar, or equiaxed) and the length scale of the microstructure (interphase spacing, e.g., dendrite arm spacing and eutectic lamellar spacing); d) *the nanoscale* ( $10^9$  m) describes the morphology at the atomic level. At this scale, nucleation and growth kinetics of solidification are discussed in terms of the transfer of individual atoms from the liquid to the solid state. Features such as dislocations involving changes at atomic level are observed with different techniques (SEM, TEM, HRTEM, FIB, etc). Modeling (deterministic or/and probabilistic) supports all solidification scales. The dialogue between experiments and models has been extremely fruitful toward successful modeling of solidification microstructures. Professor Stefanescu belongs to a golden generation of solidification theoreticians and experimentalists (Dr. W.J. Boettinger, Dr. J.W. Cahn, Dr. S.R. Coriell, Dr. G.B. McFadden, Prof. A. Karma, Prof. S. Kobayashi, Prof. W. Kurtz, Prof. M. Rappaz, Prof. R. Trivedi, etc.) and stands out like a prominent figure with major advances in both theoretical and experimental field.

### **Thermodynamic Properties of Iron, Al and Cu-base Alloys**

Not only was Professor Doru Stefanescu Volume Chair for Volume 15: *Casting*, of the 9<sup>th</sup> Edition *Metals Handbook* [10], he also contributed articles on thermodynamic properties of Fe-base as well as Al and Cu-base alloys. The structure and properties of cast metals are sensitive to numerous impurities. For example, purification of melts generally adds considerable cost to castings. Besides careful selection of metallic scrap, S and O removal from cast iron and steel, or alkali and alkaline earth elements removal from aluminum are highly desired. The structures and properties of steel and cast iron also depend on the control of the solidification structure in castings. It is then absolutely necessary to understand and control the thermodynamics of the liquid and solid phases as well as the kinetics of solidification (nucleation and growth of various phases). Knowledge of activities and activity coefficients is necessary in describing solution behavior and in solving problems that involve chemical equilibria. The thermal properties are useful in understanding the liquid state and solution behavior. The activity coefficients provide simple means of calculating the inter-diffusion coefficients and are used to correlate experimental data on dilute solutions. Calculation of solubility lines which are relevant to the construction of phase diagrams, the calculation of the activity of various components which in turn determines knowledge of probability of formation and relative stability of various phases, are factors that influence casting and solidification processes. Alloying elements are also considered in terms of their influence on the activity of carbon, which provides information on the stability of the main carbon-rich phases of iron-carbon alloys (graphite and cementite). Correlating all these elements becomes of tremendous importance in guiding the processes of casting and solidification.

## Summary

Instead of a regular summary, we would rather quote one of Professor Doru Stefanescu close collaborators, Dr. Roxana Ruxanda [11]: “In the years passed, I witnessed first-hand some of his endeavors and I learned how much effort and dedication were invested in his undertakings. For as far as I know, I am certain of one thing: I should be better prepared to be excited by many of his future accomplishments.” And more: “I know that he is very happy when his former students are successful; I know that he takes great pride in being one of the first to really understand the importance of the cooling curves and their interpretation. His research projects with *NASA* were very unconventional. Although his research made him well known in the field, he seemed to have enjoyed the most his teaching and interactions with his students.” Professor Doru Stefanescu’s contributions to metallurgy are very well outlined by his nomination for the *ASM Fellow* award, 1997. He was cited “for fundamental contributions to the science of solidification through the modeling of solidification processes and the microstructural evolution of castings.” Congratulations Professor Doru Stefanescu for all your achievements and great volunteering work with the ASM International.

## References

1. D.M. Stefanescu, *Science and Engineering of Casting Solidification*, (New York, NY: Second Edition, Springer, 2009), 402 pages.
2. John Morral: Personal Communication.
3. D.M. Stefanescu, “Classification and Basic Metallurgy of Cast Iron, Properties and Selection: Irons, Steels, and High Performance Alloys”, *ASM Handbook, vol. 1*, (ASM International, OH: American Society for Metals, 1990), 3-11. Updated and revised by D.M. Stefanescu, under the direction of the ASM Handbook Committee, 2014.
4. D.M. Stefanescu, “Compacted Graphite Iron, Properties and Selection: Irons, Steels, and High-Performance Alloys”, *ASM Handbook, vol. 1*, (ASM International, OH: American Society for Metals, 1990), 56–70.
5. D.M. Stefanescu and R. Ruxanda, “Fundamentals of Solidification, Metallography and Microstructures”, *ASM Handbook, vol. 9*, (ASM International, OH: American Society for Metals, 2004), 71–92.
6. D.M. Stefanescu and R. Ruxanda, “Solidification Structures of Steels and Cast Irons, Metallography and Microstructures”, *ASM Handbook, vol. 9*, (ASM International, OH: American Society for Metals, 2004), 97–106.
7. D.M. Stefanescu and R. Ruxanda, “Solidification Structures of Aluminum Alloys, Metallography and Microstructures”, *ASM Handbook, vol. 9*, (ASM International, OH: American Society for Metals, 2004), 107–111.

8. D.M. Stefanescu and R. Ruxanda, “Solidification Structures of Titanium Alloys, Metallography and Microstructures”, *ASM Handbook*, vol. 9, (ASM International, OH: American Society for Metals, 2004), 116–126.
9. D.M. Stefanescu and R. Ruxanda, “Computer Modeling of Solidification Microstructures, Metallography and Microstructures”, *ASM Handbook*, vol. 9, (ASM International, OH: American Society for Metals, 2004), 127–131.
10. D.M. Stefanescu and S. Katz, “Thermodynamic Properties of Iron-Base Alloys, Casting, ASM Handbook”, *ASM Handbook*, vol. 15, (ASM International, OH: American Society for Metals, 2008), 41–55.
11. Roxana Ruxanda: Personal Communication.