Electromagnetic Processing of Materials

FLUID MECHANICS AND ITS APPLICATIONS
Volume 99

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Electromagnetic Processing of Materials

Materials Processing by Using Electric and Magnetic Functions

Springer

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Preface

Most people who choose to read this book are likely to begin with the question "What is ***Electromagnetic Processing of Materials?"*** This question is a reasonable one since ***Electromagnetic Processing of Materials,*** so called ***EPM***, will find its future development in concert with ***Materials Science and Engineering***, a conjoining of areas of research that has not yet been fully consummated.

In the metals industry, utilization of the *Lorentz* force started in very early times; for example, machines to effect electromagnetic levitation and electromagnetic mixing were invented in 1923 and 1932, respectively, but with little understanding of the science behind them. To bridge the gap between technology and science, the term ***Magnetohydrodynamics***, which had been established by *Alfvén* in 1942, was first introduced at the IUTAM (International Union of Theoretical and Applied Mechanics) symposium entitled "Metallurgical Applications of Magnetohydrodynamics", held in 1982 in Cambridge, England. Thus, we can say that ***Electromagnetic Processing of Materials*** started from this symposium where the two channels of ***Metallurgy*** and ***Magnetohydrodynamics*** were combined. The term ***Electromagnetic Processing of Materials*** first appeared at The Sixth International Iron and Steel Congress held in 1990 in Nagoya, Japan and then the first Symposium of ***EPM*** was held in 1994, also in Nagoya. That is, ***EPM*** started in the 1980s and grew in the 1990s as an intimate collaboration between France and Japan. The first fruits of EPM progress were found in utilization of the *Lorentz* force, mainly for development of steelmaking processes, especially of continuous casting processes. By the 2000s the activity of ***EPM*** had spread into the utilization of magnetization force, enabled by the fortuitous fact that a high magnetic field, up to around 15 Tesla, became easily available through the development of super-conducting technologies. Briefly speaking, ***EPM*** is now located in one branch of ***Materials Science and Engineering*** and aims to create new materials and/or to design efficient processes by making use of various functions which appear when electric and magnetic fields are applied to known materials.

This book contains not only an English translation of my book on Electromagnetic Processing of Materials first published in 2000 by Uchida Rokakuho, Japan, the content of which is based on the lectures given for advanced undergraduate and

graduate students in the Department of Materials Science and Engineering, Nagoya University over two decades, but also the introduction of transport phenomena. Furthermore, tables and appendix are added for helping the design of electromagnetic processes, and better understanding of the contents of the book. In Chap. 1, the birth, characteristics and prospects of ***EPM*** are described to give readers a brief summary of what ***EPM*** is. In Chap. 2, the concept of ***Transport Phenomena,*** which is indispensable in materials processing, is given a concise introduction in order to establish that the transport phenomena of mass, heat and momentum can all be described by the same diffusion type equation. In Chap. 3, I describe the essentials of ***Magnetohydrodynamics*** that are required for understanding ***EPM*** and I show that the governing equation of a magnetic field can also be expressed by the same diffusion type equation as introduced in Chap. 2. That is, it is understood that the concept of transport phenomena holds not only in relation to heat, mass and momentum, but also in magnetic fields. Though many mathematical equations appear in this chapter, for the sake of developing a stricter analysis, I recommend that the beginner in EPM read until Chap. 5 by skipping derivation of equations. After that, readers should again read the skipped Chapters. In Chap. 4, the various functions that appear when applying electric and magnetic fields to materials are enumerated and their utilization in materials processing is explored. Recently, due to advances in superconducting magnets, a high magnetic field has become readily available and is being applied in various fields of science. In this trend many interesting phenomena relating to high magnetic fields have been found and a new academic area called ***Magneto-Science*** has begun to open a gate to further research. In order to connect the seeds sprouting from the new academic field with the needs of ***Materials Science and Engineering***, a new branch of ***EPM*** is growing. Thus, in Chap. 5, materials science and engineering utilizing a high magnetic field is introduced and the functions that appear when applying a high magnetic field to materials processing are explained.

EPM has only recently been recognized as a cutting edge technology. If publication of this textbook leads to opening a new academic field in ***Materials Science and Engineering***, and becomes universally known as ***Electromagnetic Processing of Materials,*** it will deepen my great pleasure as one of the persons who have participated in this field from the beginning. Especially, I would like to dedicate this book to the late Dr. Marcel Garnier of the EPM-MADYRAM in Grenoble, France, who first initiated and developed this field together with me.

I am indebted to many people for help of one kind or another in the making of this book. I am especially grateful to the late Professor Iwao Muchi at Nagoya University and the late Professor Julian Szekely at MIT, who taught me the basis of **Metallurgical Reaction Engineering** and **Magnetohydrodynamics**, respectively. Those academic backgrounds prompted me to write this book. Professor Emeritus Tsuyoshi Masumoto of Tohoku University, Japan always has encouraged us in developing this field by nominating the EPM subject to a place in the science and technology program in The Ministry of Education, Culture, Sports, Science and Technology, Japan. Professor Emeritus René Moreau of SIMAP/EPM in Grenoble, not only gave useful academic advice regarding the problems of Magnetohydrody-

namics, but also kindly arranged a contact with Springer to publish this book. The Professor Yves Fautrelle of SIMAP/EPM in Grenoble and Professor Shoji Taniguchi of Tohoku University have devoted a lot of effort for developing EPM with me for a long time. Above all, the author would like to thank Professor Ken-ichi Miyazawa of Nagoya University who painstakingly read each draft, querying every ambiguity and exposing the many inconsistencies in the original manuscript. Careful reviews of the final manuscripts contributed crucial descriptions of the academic viewpoints of Profs. Noboru Yoshikawa and Kazuyuki Ueno of Tohoko University, Kazuhiko Iwai of Nagoya University and Hideyuki Yasuda of Osaka University. In this sense I am not the only author of this book, but share that role with all of my colleagues in world EPM community.

Despite this help, errors and obscurities undoubtedly remain. I would be most grateful to anyone who brings them to my attention at one of the addresses below.

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