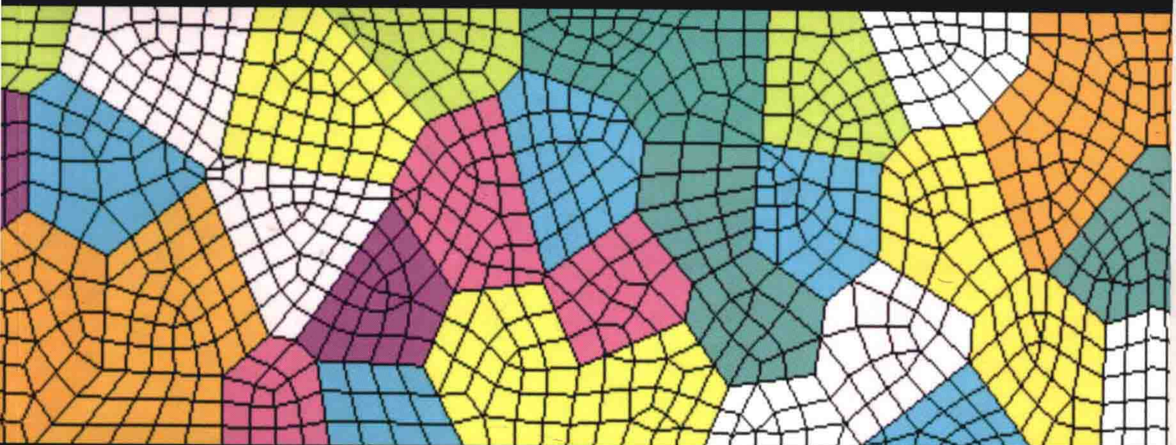
Fundamentals of Materials Modelling for Metals Processing Technologies



THEORIES AND APPLICATIONS

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Preface

It is a particular pleasure for me to write the preface for this extraordinary book. Professor Lin has devoted many years to the development of numerical simulations of metal forming processes, and their verification experimentally. Prior to this work metal forming modelling was a mechanics exercise in which simple material models were used. The materials inputs were limited to elastic-plastic stress–strain curves with work hardening but no consideration of microstructure. Here, the subject has been taken forward by including the details of the evolution of the microstructure to achieve particular properties in the finished product. This is a major advance which is reflected in the large scale support the work has received in recent years. It is also a considerable intellectual achievement requiring a sustained effort over many years. I believe the book will be seen as a milestone in manufacturing and plasticity technologies.

Professor Gordon Williams
FREng, FRS
Imperial College London, August 2014

Introduction

For modern engineering applications, formed metal components are required to be manufactured with specified microstructures, mechanical and physical properties so that their performance characteristics and useful lifetime are assured. Material and process models, which characterise microstructural evolution in addition to process mechanics, have been developed to facilitate this requirement. Efforts have been made over many years to advance classical mechanics of materials models to achieve the goal. These advances have resulted in unified materials descriptions, which enable mechanical and physical phenomena arising in work-pieces during large deformation metal forming processes to be modelled.

The main purpose of this book is to present the state of the art in material and process modelling in a manner that makes it useable for development engineers to improve production processes and quality of formed metal parts. It is designed for readers who already have some basic knowledge of solid mechanics, the theory of plasticity and metal forming processes and are familiar with numerical methods and computing techniques. It is suitable for undergraduates, postgraduates and industrial engineers. Also, it is intended to be useful to academic supervisors and project managers.

The main focus here is the development of unified materials modelling theories for analysing mechanics and microstructural evolution problems encountered in metal forming processes. However, to cover a more general theme, the chosen title of the book is "Fundamentals of Materials Modelling for Metals Processing Technologies – Theories and Applications". Many metal processing operations do not involve bulk large plastic deformation, such as friction stir welding (FSW), inertia welding, heat treatment of materials (e.g. solution heat treatment followed by quenching), laser joining and cutting. In these cases small scale plastic deformation takes place due to mechanical and thermal loading and microstructure evolution occurs at high temperature under complex stress and strain conditions. Process mechanics and dynamic microstructural evolution phenomena can be modelled for these processes also, using the unified theories introduced in this book. Some of the examples given to guide the reader in the use of models and techniques appropriate to particular processes, relate to work carried out in the Metal Forming and Materials Modelling Group at Imperial College London and earlier at the University of Birmingham. For example, unified viscoplastic constitutive equations have been created to model the mechanics and microstructural evolution in inertia welding of RR1000 superalloys and bainitic steel (Shi, Doel, Lin, *et al.*, 2010).

A wide field of knowledge is covered, dealing with fundamentals of materials modelling, particularly the formulation of unified constitutive equations for metal processing technologies from macro to micro lengthscales. Inclusion of the numerous subjects related to modelling requires explanations to be concise and for more details readers should refer to relevant publications, which are listed in the references.

The contents of the book comprise an introduction to unified materials modelling theories and related practical engineering applications. They include fundamental mechanics theories, basic material and metallurgical knowledge, deformation and failure mechanisms and explanations of how they may be used to construct materials and process models to be used in computer-based process simulation of metal forming processes. Also included are crystal plasticity theories which are used in micro-forming simulation. The book is divided into four distinct parts:

- *Fundamental knowledge of metal forming techniques, mechanics and materials*. This comprises Chapters 1 and 2 and introduces the basic knowledge required for understanding how to formulate and efficiently characterise materials and undertake analyses of manufacturing processes based on the plastic deformation of metals. It aims particularly to educate young students, researchers and engineers working within diverse fields of metal forming research and applications.
- *Formulation and application of unified constitutive equations*. The second part of the book includes Chapters 3, 4, 5, 6 and 7, and introduces fundamental techniques for formulating and determining unified constitutive equations. Application domains for plasticity (Chapter 4) and viscoplasticity (Chapter 5) have been defined for different processes. This is important to enable young researchers and industrial engineers to choose the right theory for

their particular applications. Material deformation and failure mechanisms for various deformation conditions and the theories for modelling individual process phenomena are introduced in detail in Chapter 6. Finally, numerical techniques for solving and calibrating unified constitutive equations are introduced in Chapter 7. This chapter is mainly for advanced researchers at universities and research institutes.

- *Application examples*. Examples, based on results from projects sponsored by industry, of applying the theories to practical engineering processes, are introduced in Chapter 8. These case studies are designed to help students, academic researchers and engineers to gain insight of techniques for using the theories and applying them appropriately to particular processes.
- *Crystal plasticity and micro-forming applications*. Mode of deformation, size of product and grain size are very important factors influencing the outcomes of micro-forming processes, but macro-mechanics theories often are not applicable to micro-forming applications. Thus crystal plasticity theories, based on slip systems in lattice structures, are introduced. Chapter 9 is mainly for researchers working on micro-mechanics technologies, including micro-forming and micro-machining. Also it is designed to help researchers working on fracture mechanics. It is an aid to understanding basic plastic deformation mechanisms.

The book has been written with the support of many people. My wife, Yuqin, has provided every opportunity for me to work on the book during a busy time in which I was supervising various research projects. Without her support, it would not have been possible to complete the book. In addition, my daughter, Kelly, and her husband, Edward, have spent their valuable time to undertake proofreading, which was hard work for them, since they are economists.

Professor Trevor Dean of the University of Birmingham, who is a well-known expert in metal forming technologies, has provided constructive suggestions for the book and gave me much advice and encouragement. He also helped me by reading and correcting most of the chapters of the book. To enable me to concentrate on the book writing, Professor Dean helped supervise my PhD students by reading and correcting their theses. Professor Gordon Williams of Imperial College London, who is a well-known research leader on mechanics of materials, has also spent his valuable time to proofread and comment for many chapters for the book. Professor Anthony Atkins of University of Reading also helped. Their efforts and support are greatly appreciated.

I give thanks to the many members and former members in the Metal Forming and Materials Modelling Group who have helped in proofreading chapters, checking equations, drawing figures, providing photographs and dealing with the many small details necessary to produce a quality book. These researchers include (in alphabetical order): Dr Qian Bai, Dr Jian Cao, Mr Omer El Fakir, Mr Haoxiang Gao, Mr Jiaying Jiang, Miss Erofili Kardoulaki, Dr Morad Karimpour, Dr Michael Kaye, Mr Aaron Lam, Dr Nan Li, Dr Jun Liu, Dr Mohamed Mohamed, Dr Denis Politis, Mr Nicholas Politis, Mr Zhutao Shao, Dr Zhusheng Shi, Dr Shiwen Wang and Mr Kailun Zheng. Particularly, major editing work has been carried out by Dr Zhusheng Shi of the Group.

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23 August 2014 at Imperial College London

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