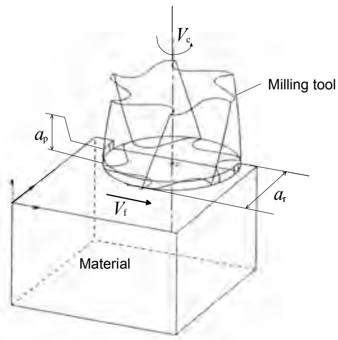
Introduction

This book deals with the solution of heat transfer problems in material-forming processes, more particularly metal-forming processes. It is aimed at students and engineers involved in the field of design and production. Various reading levels are possible. On the one hand, the reader eager to apply the results presented in this book will be able to refer directly to the corresponding chapter. On the other hand, the reader anxious to grasp each detail of a solution will find concise demonstrations in the form of corrected exercises. The reader should note that, whatever the reading level, he/she must master the basics of heat transfers as set out in Chapter 1.

Material forming is a structural transformation that is made possible by the production of heat and work in a process.

Molding of metal alloys: molding is an old art which has evolved dramatically due to the increasingly complex shapes required and the advanced technologies involved (such as mold prototyping).



Removal of material through milling: cutting is one of the processes most used to achieve precise geometrical forms and good surface quality. Recently, these types of processes have evolved dramatically with high-speed machining and the use of composite coatings on tools.

Welding and laser cutting: the laser is used nearly everywhere today. It represents a cost-effective alternative in applications requiring high speed and extreme accuracy. This technology even makes it possible to achieve complex and variable geometrical forms.

Two scales of observation clearly stand out in the analysis of a process. The first observation scale involves the process in its entirety. It integrates both the material and the forming machine used. On this scale, the system is usually contemplated as a black box, and the mass, momentum and energy balances between the input and output of the box are investigated. It may be required to consider the heat sources involved in the process (e.g. in the case of a chemical reaction). The balances established on this scale make it possible to optimize the mechanical and thermal parts of the machine according to the power to be applied to deform the material into the desired shape within the prescribed time. This observation scale does not provide any information about the mechanical and thermal loads imposed on the material at any point and any moment. Knowledge of these loads is however necessary for many reasons. In particular, it is always important to check that the values reached remain below the critical values which lead inexorably to destruction of the material or, to a lesser extent, to deterioration of the thermomechanical properties.

The observation scale used in this book involves the worked material itself, and this study focuses more particularly on heat transfers.

In practice, engineers often try to solve thermal problems “manually”. This work demonstrates that reliable analytical solutions can be obtained using advanced techniques for solving heat equations. In particular, Chapter 1 demonstrates the value of using integral transforms such as the Laplace transform. Chapter 4 shows that problems in associating heat transfers with mass transfers can be solved by considering the configuration of moving heat sources. The analytical solutions presented have been simulated using the MATLAB software. Many codes are listed at the end of each chapter; they will allow the reader to quickly understand the solutions and adapt them to their own configurations.

When much more accurate solutions are required, spatial-temporal discretizations of partial differential equations must be used. Many software packages, based in particular on the finite element method, have been developed for the forming industry. These powerful tools make it possible to formulate a minimum of approximations with regard to the actual configuration studied. Nevertheless, the reader has to keep in mind that their implementation is time-consuming and requires computer resources adapted to the required computing power. It will thus be necessary for the engineer to define the appropriate solving method according to the configuration studied, and especially according to the desired precision.

The following gives an overview of the structure of the book. Chapter 1 describes the various heat transfer models applying to diffusion, convection and radiation. This chapter also defines the traditional boundary conditions and initial conditions. Finally, it presents the Laplace-transform solution to the heat diffusion equation in transient mode.

Chapter 2 provides a reminder of the finite element method and addresses the application of this method to the solution of the heat transfer models in transient mode. The method is described for the sake of practical application. This chapter also describes the numerical algorithms traditionally used to solve large-scale linear systems with sparse matrices. The FEMLAB Multiphysics simulation software is used in the applications developed in Chapters 3 and 4.

Chapter 3 is dedicated to the modeling of heat transfer in metal alloy molding. The primary goal of this chapter is to demonstrate the usefulness of the thermal models for the prediction of defects likely to appear during solidification. This chapter begins by defining the concepts of phase change, phase diagram and phase change enthalpy. First, analytical solutions are presented for various configurations of 1D heat transfer: insulating mold (sand mold), conducting mold (chill casting), imperfect mold-alloy contact, etc. Then, this chapter applies the finite element method to a real configuration and shows how the geometry of the mold can be changed to avoid the appearance of defects during solidification of the alloy.

Chapter 4 discusses the modeling of heat transfer in machining processes such as cutting, welding and laser treatment, as well as grinding. Again, analytical solutions are presented and compared with those obtained using the finite element method. In some configurations, the results obtained analytically are often very close to those obtained using the finite element method. In some other configurations, the significant difference between both approaches justifies the implementation of the numerical method.

Obviously, it was impossible to investigate the heat transfers occurring in every forming process. The objective of this book is to supply the reader with resolution and modeling tools which, once adapted, will enable him/her to solve his/her own configurations. I hope that the examples provided in this work will represent a sufficient source of motivation.

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