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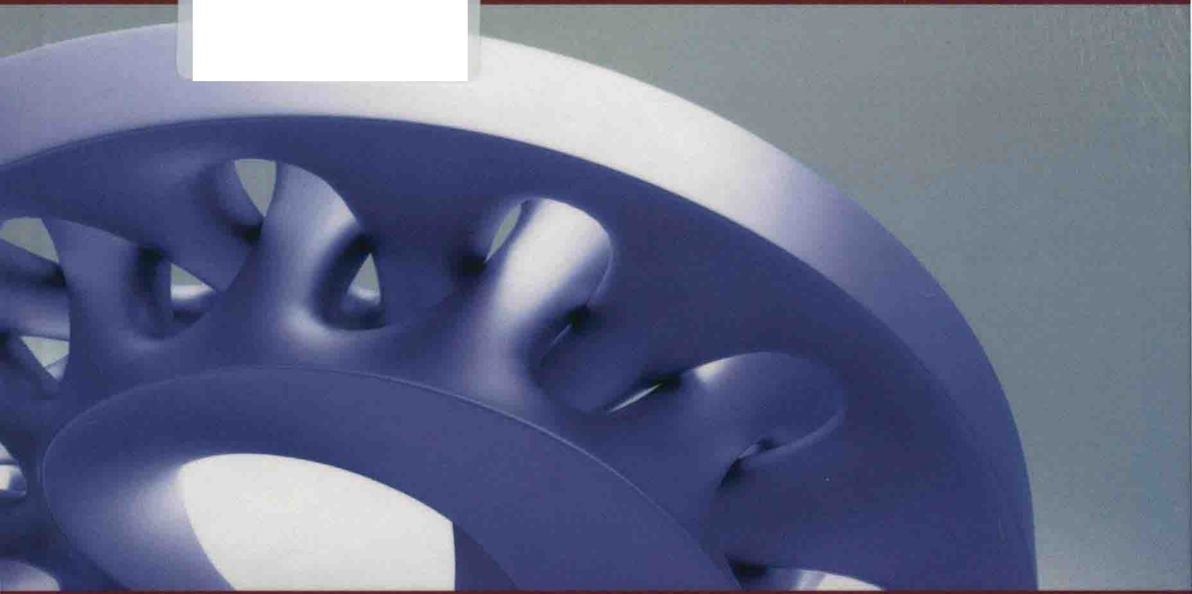

Volume 1

Material Forming Processes

Simulation, Drawing, Hydroforming and Additive Manufacturing

Bouchaib Radi

Abdelkhalak El Hami

iSTE

WILEY

Mathematical and Mechanical Engineering Set
coordinated by
Abdelkhalak El Hami

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Material Forming Processes

Preface

In the current economical climate, the automotive, aviation, aerospace, defense, etc., industries have established the following priority: improve the quality and the reliability of products while reducing production costs. To achieve this goal, the industry strives to modernize its work tools in order to minimize the duration of design cycles and improve manufacturing processes.

The field of metal forming (stamping, thin sheet metal deep-drawing, tubes and plates hydroforming, forging of solid materials, cutting, composite draping, foundry, etc.) is the subject of much research and of different courses destined to engineers and academics (as part of masters and doctoral schools). This interest is due to the increasing demands from different industrial sectors for graduates with experience in these disciplines.

In different industries (automotive, aeronautics, etc.), metal forming constitutes, in the course of the entire manufacturing processes, a decisive phase in the overall quality and cost of the final product. A vehicle is first judged on its design.

Currently, numerical simulations of forming processes are being used almost systematically in the development of industrial products. The studies, based on the modeling of physical phenomena involved in the manufacturing or the utilization of industrial products or infrastructures, answer the growing need to:

– decrease the duration of the product development cycle;

– optimize product development procedures;

– improve the productivity in design and manufacturing phases;

– improve product quality and process reliability;

– optimize testing and reducing its costs;

– simulate non-reproducible complex phenomena by means of trials.

The use of digital educational tools maintains a strong relationship with the training and research strategy (http://mediamef.insa-rouen.fr/).

This book presents the various methods for forming used in the industry: stamping, hydroforming and additive manufacturing and proposes a modeling of the latter by providing the theoretical and numerical advances for each process involving large deformation mechanics on the basis of large transformations. It presents the various techniques relative to the optimization and calculation of the reliability of different processes.

Acknowledgments

We wish to thank everyone who has directly or indirectly contributed to this book, in particular the engineering students and the PhD students of the INSA Rouen that we worked with in recent years.

Bouchaïb RADI
Abdelkhalak EL HAMI
June 2016

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1

Forming Processes

1.1. Introduction

The field of metal forming comprises a wide range of semifinished and finished products. Each requirement of the acquisition criteria is defined, justifying the use of various forming processes. A number of recurring characteristics can be observed in the desired shapes. The latter should respond with the best dimensional precision possible and the most suitable surface condition for its usage. The final product must meet material health conditions for usage properties with the least possible continuity defects. There is, therefore, an interest in what the most appropriate macro- and microstructures are.

1.2. Different processes

Metallic materials offer a rich range of independent or combined forming methods. Among the large families, the following processes are identified:

– smelting;

– machining;

– powder metallurgy;

– hot or cold plastic strain forming.

Each of these processes present characteristics of optimal quality, variable depending on the material being used, on the dimensions and on the desired accuracy, on the metallurgical quality, on the final cost and on the quantity. The choice is oriented according to specific criteria:

– the abilities of the material in relation to the different processes (particular attention should be given to the difference between a foundry alloy and alloys deemed "wrought") regarding the form and the dimension of the product;

– the defined metallurgical health (limitation of defects such as cracks, porosities and chemical segregations);

– the usage properties of the product in the mechanical field;

– the desired surface condition (in terms of cleanliness, roughness, of residual stresses, etc.).

1.2.1. *Smelting*

The metal or the alloy is melted inside a crucible and then it is poured into a specific mold inside which it will solidify when cooled down. Complex forms can be obtained often linked with a minimum of induced thickness. Large variations of the latter involve consequences on the development of the final properties. Casting workpieces are produced from simple and often fairly cheap traditional techniques. This results in obtaining monobloc parts whose quality and mechanical properties are lower than those of wrought products (products having undergone hot hammering in order to obtain the desired properties often in a compulsory direction). There are numerous and very varied molding techniques depending on shape, quantities and on the quality requirements:

– The mold is made up of sand and inside it a cavity can be found that will represent the resulting piece. The first operation consists of building a pattern generating the shape of the desired casting by integrating the machining allowances and the useful drafts. The pattern represents the mold cavity left in the sand when the mold is closed. The mold is opened to extract the pattern therefrom and closed to the molten metal. When solidification is achieved after slow cooling, the mold is broken in order to retrieve the final product. One casting is thus obtained per mold.

– The mold is in metal and thus is reusable. The cooling proves to be much faster than the sand casting process. The pattern is obtained by machining the mass and with respect to the hollow parts, they can be achieved with eventually destructible cores.

– Die-casting integrates a metal mold but the filling of the pattern is ensured by means of a piston that pushes the liquid at high speed in a short period of time (a few 1/10 of a second). A slight overpressure can be maintained in the mold, which has the effect of properly feeding the pattern, while avoiding the design of a hot-top to perform this function. The mechanization of the process is total. On the other hand, the tools undergo very significant repeated efforts, which reduces their life expectancy (20, 000–50, 000 parts depending on the nature of the cast alloy).

– Centrifugal casting concerns all so-called revolution parts. The fundamental difference lies at the level of the introduction of liquid material, which is carried out along an axis around which the mold revolves. The centrifugal force promotes uniform filling. The structural composition is finer and full.

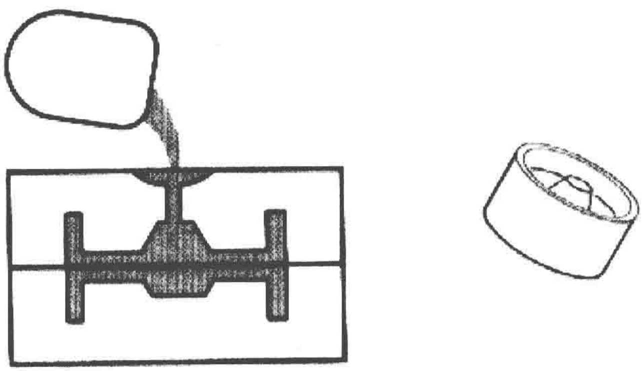

Figure 1.1. *Gravity die casting accompanied by the obtained casting*

1.2.2. *Machining*

Machining is a material removal operation making use of a cutting tool. This process allows for highly accurate complex forms and a controlled surface finishing. Different processes are identified and classified into two large categories. The first involves chip formation, which mainly includes turning, milling, grinding and drilling. The second does not involve chip formation and designates flow-turning, electrical discharge machining, shearing and waterjet cutting. From a structural point of view, machining only alters a superficial layer of the material, which therefore causes a hardening of the surface. As a result, we can observe the creation of a residual sublayer stress field, causing significant heating in the superficial layer. Ease of machining is linked to the physical contact of the tool-workpiece pair during machining. It depends not only on the mechanical behavior of the material (resistance, consolidation and malleability of the machined material) but also on its thermal behavior. A low resistance is recommended, which means a sufficient malleability, however this facilitates chip breaking. It can also be noted that a good thermal conductivity most often facilitates the machining. As a result of adding cold or hot particles, the cutting conditions can be improved (controlled inclusions of low melting point lead or even sulfides, etc.). These latter facilitate the fragmentation of the chip:

– *Chip formation*: Machining takes place following optimized cutting conditions, which consider the geometry of the cutting tool, the cutting fluid and the dimension of the non-deformed chip. It is formed following primary shearing of the metal when making contact with the cutting edge of the tool and following a secondary shear when in contact with the external edge of the tool. This effort zone undergoes superficial strain hardening and heating. In addition, the chip is subjected to the same efforts coupled to the tool on its external edge. Futhermore, the cutting speed V_c plays a paramount role and is thus expressed:

$$V_c = \frac{n.\pi.d}{1000}$$

with V_c expressed in m/min, rotational speed in rpm and tool diameter for milling.

– *The machined surface*: It is defined by a heated and hard-tempered underlying superficial area. The microstructure can therefore be modified (constituents or phase change) or even undergo local strain hardening by cold working. Often, there remains a significant local residual stress field. Moreover, microcracks can be observed.

– *The chip*: When the material is fragile, it quickly becomes fragmented into lemels (for example some smeltings). In the event that it is ductile and slightly consolidates. However, when this consolidation occurs as a result of the hardening phenomenon, it easily fragments. On the other hand, a few obstacles to chip formation may surge notably due to heating and pressure. A galling phenomenon can be observed between tool and chip forming a build-up edge. It is defined by lemel stuck to the tool. Thus, the maximal temperature is variable according to the cutting speed and the hardness of the tool. The stress and strain field induced by the cutting enforces an increase in the temperature of the metal.