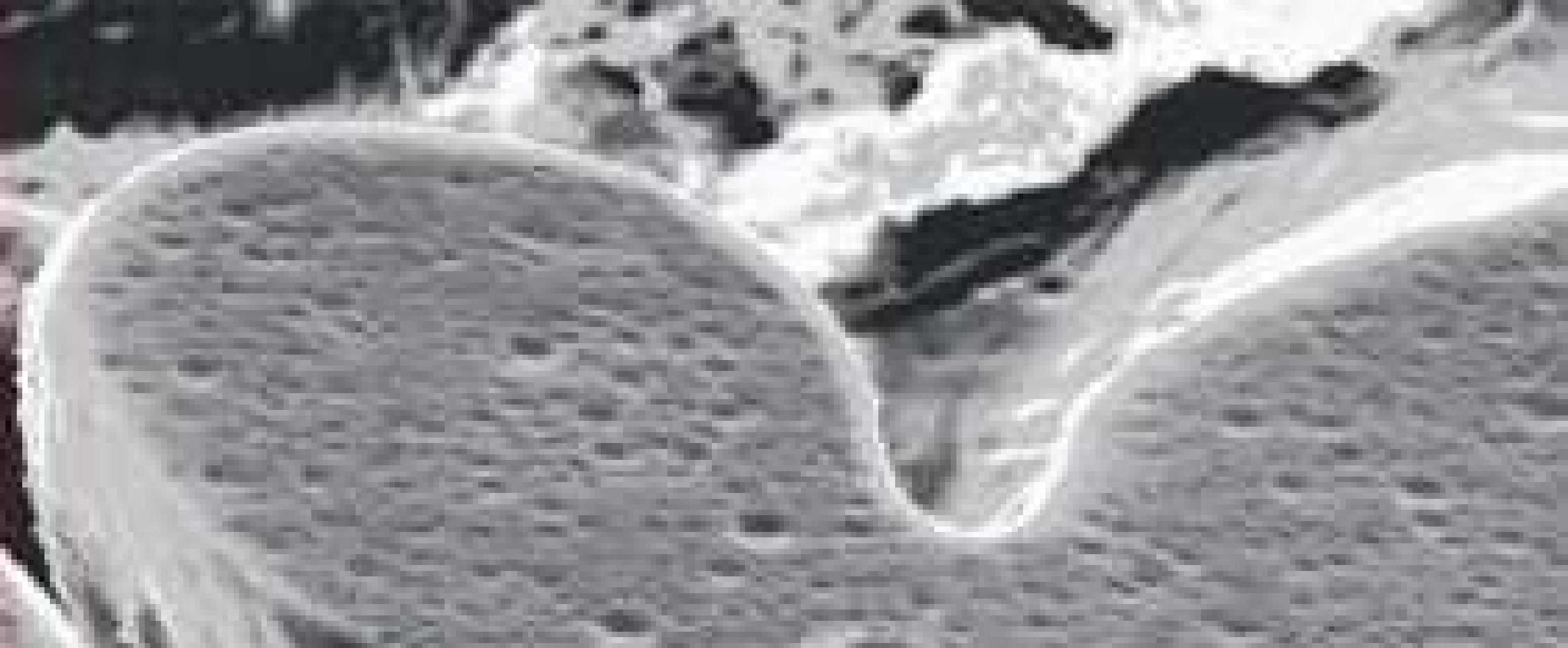

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Metallurgy and Processing of High-Integrity Light Metal Pressure Castings

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Priv.-Doz. Dr. Helmut Kaufmann

Managing Director, ARC Leichtmetallkompetenzzentrum Ranshofen GmbH (LKR), Austria
Head of Division
“Materials Technologies“, Austrian Research Centers GmbH (ARC)
College Lecturer, Technical University Aachen (RWTH), Germany
and ETH Zürich, Switzerland

Prof. Dr. Peter J. Uggowitzer

Professor of Physical Metallurgy,
Department of Materials, ETH Zurich, Switzerland

This book is based upon the Habilitation Thesis of
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Executive Summary

High-quality casting is a successful synthesis of material science and applied casting technology, which is itself a combination of knowhow from mechanical engineering, process engineering, applied physics and chemistry.

This book is an attempt at a complete overview of light metal alloy pressure casting technology, intended to provide the reader with an insight into this wide field, which is sufficiently deep to at least understand its complexity. For this reason, the text is a deliberate mixture of the scientific and the technical: both a manual for engineers in their practical daily work, and a textbook for students carrying out degree work in materials science and technology.

This volume about modern pressure casting technology rests on the strong foundations of scientific literature and practical experience. The literature on the subject is vast, since strictly speaking the materials science of light metals and foundry process technology should be considered in its entirety. Legitimately, papers on lubricant chemistry and vacuum technology, furnace and heat treatment technology and many other scientific and technological fields of interest should also be taken into account. A mountain of papers have been published, and every day new publications on the subject or related areas appear somewhere on the planet.

The authors wish to indicate from the outset that this work does not attempt a full review or discussion of this literature, but of the large research area of pressure casting. Important publications are nevertheless cited where they were essential for the development of a technology or a fundamental understanding of processes, in order to see the results in perspective to our own work and practical experience.

The authors hope that no important papers have been excluded and apologise to all authors performing valuable research who received no mention in this compilation of papers. Naturally, researchers tend to prefer the latest, the “hottest” results in the field. Therefore the literature of the past five to ten years has received the most attention, and been discussed the most here.

The High Pressure Die Casting process (HPDC) had its 100th birthday in the year 2005. Significant progress was made during this period in this very complex field of expertise. Even though much has been written about pressure casting in the past, there is still room for a book which takes a comprehensive look at the combination of mechanical engineering and materials science in pressure casting. The authors experienced great personal pleasure when studying the famous textbooks “Castings“ and “Castings Practice“ by John Campbell [Cam03, Cam04]. These two books focus mainly on melt quality and gravity die casting, but are also essential literature for any foundry man. These two books inspired the authors to do something similar for HPDC, which lacks profound textbook attention.

The main focus of well-known existing books is generally the equipment of pressure casting, rather than the metallurgical aspects. At another extreme are textbooks in

Materials Science and Physical Metallurgy, which are very theoretical and are probably not referred to by foundry engineers in their daily business.

In the late 1980s and during the 1990s the main focus of HPDC development was on pressure casting machines. Sophisticated new equipment such as HPDC machines with hydraulic shot control, vertical squeeze casting machines and various semi-solid casting machines were developed. The authors tend to call this period "the decade of mechanical engineering in pressure casting". In the same period the geometrical complexity of pressure castings and the technical requirements became more severe than ever. Parts became larger and thinner, and needed to be strong, ductile, weldable, heat-treatable, pressure-tight, and inexpensive. Confronted with these requirements, foundry men have realised that despite the modern equipment available, the limits of castability are often exceeded.

This is where pure mechanical engineering comes up against a wall. To solve the problems of the modern foundry business, a process chain approach with specific attention to materials science must replace it. It is this approach upon which this book is based. It addresses not only the principles of pressure casting, but also the effects of melt quality, alloy composition, filling conditions, and post-processing aspects such as heat treatment.

We hope that the reader will enjoy the story, and profit as much as the authors did from the Campbell books.

1 Introduction

In 1905, more than 100 years ago, High Pressure Die Casting (HPDC) came into existence when the first die casting machine by that name was patented in the USA by H.H. Doehler. Two years later E.B. Wagner came out with a prototype of the now familiar hot chamber die casting machine [Sim97]. The first significant use of HPDC was in the production of gas mask parts during World War I. Originally only zinc was used in HPDC, but by 1915 large quantities of aluminium HPDC were already being produced [Vin03].

One hundred years later, HPDC of light metals has become a fully accepted process in the metal casting industry and is applied in basically all areas of mass production. One important user of this technology is certainly the automotive industry.

After a complete century of development in the field of HPDC one question must be asked: is there anything left to be done in research and development of HPDC process and materials? The answer is a clear “YES“. This book aims to clarify this, scan the current state of development and provide ideas for further research work.

There are two significant drivers of development: quality issues, and cost issues. Both can only be addressed successfully if improvements in the overall process chain and their interactions are considered. Whereas during the 1980s and early 1990s much effort went into the development of improved HPDC machines, the authors note that today more attention is paid to improving alloys, controlling metal quality and optimizing post processing (such as heat treatment).

All measures for product and process optimization must be considered from the quality and cost perspective. In this context it seems appropriate to look at some of the issues discussed in detail throughout this work.

1.1 Quality

HPDC was known for rather porous castings with low ductility and strength levels. Quality improvements were achieved via new processing or machine concepts in the production of high-integrity castings. Vacuum HPDC, Squeeze Casting and the wide field of Semi-solid Casting resulted.

While high speed casting combined with high solidification pressures were initially considered HPDC’s big advantage, it soon became evident that these turbulent, spray-like filling conditions were also the major source of casting defects. Supported by computer simulation, the die filling and solidification processes were optimized, generating improved die designs. Improvements included the gating system, air venting, temperature control, local pressurization and more. Proper die lubrication became an issue in terms of lubrication efficiency when alloys with low iron content were used, and because of their reactivity with the melt (production of reaction gas).

Only very recently have metal quality and alloy composition received proper attention in foundries. It was long generally assumed that HPDC did not produce high-integrity castings with significant ductility, and that therefore metal cleanliness was not really an issue. Cheap secondary alloys (such as AlSi9Cu3) with high iron content in the range of 1% were used. It was not possible to make safety-critical components with this system.

In the past 15 years, however, the complexity of HPDC castings has increased dramatically. Functional integration (actually a cost issue) has forced foundry engineers into new areas of application and demanded new levels of HPDC quality. Thus alloy development for HPDC, melt cleaning, grain refinement, modification, heat treatment and welding have become issues. Functional integration has also enhanced the development of tailored materials and components. Metal matrix composites (MMC) and multi-material compounds (e. g., foam inserts in castings) are some of the results.

1.2 Cost

Modern HPDC equipment is very elaborate, and therefore cost-intensive. To compensate for high investment costs, high productivity (high up-time, low cycle time, high automation grade) is of great concern. Functionally-integrated components usually require complex and mainly large dies, which are expensive. This is why the lifetime of tooling is a major issue. It is closely related to the efficiency of the die lubricant: this should protect the die, but its use should be limited for cost and environmental reasons.

Improvements in post processing (improved heat treatment, reduced quality control, less machining, improved recycling (higher yield rate)) are also required to keep the HPDC process competitive.

Generally it is necessary to develop a very stable process. The part requirements define this process, and the alloy needs. The complexity of the castings and consequently the complexity of the total technology have increased substantially over the past few years. This is a problem in the daily foundry business, because it makes it difficult to run processes with untrained staff. From a cost point of view, however, it would be simply impossible to have a group of Ph.D.s doing this.

Foundry researchers must therefore develop and establish rules for process-oriented alloy development, in combination with materials-oriented process parameters, to reach the required component quality at competitive cost. In-line quality control and immediate countermeasures for any deviation are needed to ensure continuous, highly productive automatic manufacturing of High Pressure Die Castings.

In this work the authors address the optimization of the overall processing chain in terms of alloys, process and quality control, and propose future directions of research in HPDC and related areas.

2 Component requirements for HPDC parts

Modern light-weight design in the automotive industry uses light metal castings with increasing functionality: fewer parts integrate more functions. Therefore the demands on High-Pressure Die Castings have increased steadily over the past few years. Modern HPD castings need to be strong and ductile, and heat-treatable to adjust the mechanical properties to the component needs. In automotive applications this is especially true for suspension parts. Frequently castings need to be large, thin-walled and weldable, as required in space frame nodes or door frames. But sometimes HPD castings also need to be thick-walled and pressure-tight for hydraulic or pneumatic applications. Elevated temperature properties, wear resistance and pressure tightness are important in engine applications. More than previously, HPD castings must possess a special surface quality to fulfil optical requirements or for later adhesive bonding: this is especially true for interior applications such as dashboards. Cast metal surfaces are often merely painted, or wooden, polymer or metallic layers are glued to the cast surface. Roughness and wettability are important for the latter use.

Strong, ductile and pressure-tight parts require proper alloys and castings with limited porosity and inclusions. For heat-treatable castings gas inclusions resulting from die filling, hydrogen reactions from wet foundry equipment and lubricants or carbon reactions from lubricants must be kept to a minimum. The same is true for the weldability of HPD castings. The choice of lubrication is also critical when it comes to surface quality. If large, thin-walled castings need to be manufactured cost-efficiently, solutionizing heat treatment should be avoided to reduce energy consumption for heat treatment and the rectifying operation to eliminate distortion of the castings after quenching. New naturally-ageing alloys with high strength and ductility or T5 heat treatment of existing or slightly modified alloys may be the solution.

In principle all of these requirements apply both to castings made of aluminium, and magnesium alloys. Alloy composition, melt treatment, melt handling and ladling into the machine have a significant influence on subsequent casting quality. Later die filling can only cause the quality of the melt to deteriorate, and not improve it.

The preparation of the melt, its ladling into the high pressure die casting machine and the die filling process are the parts of the processing chain where the various existing HPDC processes differ the most. High solidification pressure, however, is a property common to all HPDC processes. It is applied to enhance feeding during solidification of the melt in order to avoid shrinkage porosity. The various HPDC processes resulted from the application (and sometimes varying interpretation) of modern casting theory. Theoretical considerations concerning die filling will be provided in Chapters 3 and 4, followed by an introduction to the modern HPDC processes which resulted (Chapter 5).