



SECOND EDITION

影印版

铸造手册大全：金属铸造工艺、冶金技术和设计
第1册 熔体·卷入·流动

COMPLETE CASTING HANDBOOK

Metal Casting Processes, Metallurgy,
Techniques and Design

JOHN CAMPBELL

ELSEVIER



哈尔滨工业大学出版社
HARBIN INSTITUTE OF TECHNOLOGY PRESS

JOHN CAMPBELL

COMPLETE CASTING HANDBOOK

Metal Casting Processes, Metallurgy,
Techniques and Design

SECOND EDITION

影印版

铸造手册大全：金属铸造工艺、冶金技术和设计

第1册 熔体·卷入·流动



哈尔滨工业大学出版社
HARBIN INSTITUTE OF TECHNOLOGY PRESS

黑版贸审字08-2018-075号

Elsevier (Singapore) Pte Ltd.
3 Killiney Road, #08-01 Winsland House I, Singapore 239519
Tel: (65) 6349-0200; Fax: (65) 6733-1817

Complete Casting Handbook, 2nd Edition
John Campbell
Copyright ©2015, 2011 John Campbell. Published by Elsevier Ltd. All rights reserved.
ISBN-13: 9780444635099

This reprint of Complete Casting Handbook, 2nd Edition by John Campbell was undertaken by Harbin Institute of Technology Press and is published by arrangement with Elsevier (Singapore) Pte Ltd.

Complete Casting Handbook, 2nd Edition by John Campbell由哈尔滨工业大学出版社有限公司进行影印, 并根据哈尔滨工业大学出版社有限公司与爱思唯尔(新加坡)私人有限公司的协议约定出版。

ISBN: 9787560373362

Copyright ©2018 by Elsevier (Singapore) Pte Ltd.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from Elsevier (Singapore) Pte Ltd. Details on how to seek permission, further information about the Elsevier's permissions policies and arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by Elsevier (Singapore) Pte Ltd. and Harbin Institute of Technology Press (other than as may be noted herein).

Online resources are not available with this reprint.

Printed in China by Harbin Institute of Technology Press under special arrangement with Elsevier (Singapore) Pte Ltd. This edition is authorized for sale in the People's Republic of China only, excluding Hong Kong SAR, Macau SAR and Taiwan. Unauthorized export of this edition is a violation of the contract.

本书英文影印版由Elsevier(Singapore) Pte Ltd.授权哈尔滨工业大学出版社有限公司在中华人民共和国境内(不包括香港特别行政区、澳门特别行政区以及台湾地区)出版与发行。未经许可之出口, 视为违反著作权法, 将受民事和刑事法律之制裁。

本书封底贴有Elsevier防伪标签, 无标签者不得销售。

Notice

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary. Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds or experiments described herein. Because of rapid advances in the medical sciences, in particular, independent verification of diagnoses and drug dosages should be made. To the fullest extent of the law, no responsibility is assumed by Elsevier, authors, editors or contributors in relation to the adaptation or for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

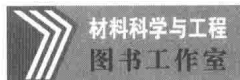
图书在版编目(CIP)数据

铸造手册大全: 金属铸造工艺、冶金技术和设计 = Complete Casting Handbook Metal Casting Processes, Metallurgy, Techniques and Design. 第1册, 熔体·卷入·流动: 英文 / (英) 约翰·坎贝尔 (John Campbell) 主编. — 哈尔滨: 哈尔滨工业大学出版社, 2018.8

ISBN 978-7-5603-7336-2

I. ①铸… II. ①约… III. ①冶金-技术-手册-英文 IV. ①TF1-62

中国版本图书馆CIP数据核字(2018)第094698号



材料科学与工程
图书工作室

责任编辑 杨桦 许雅莹 张秀华

出版发行 哈尔滨工业大学出版社

社址 哈尔滨市南岗区复华四道街10号 邮编 150006

传真 0451-86414749

网址 <http://hitpress.hit.edu.cn>

印刷 哈尔滨市工大节能印刷厂

开本 787mm × 960mm 1/16 印张 15.25

版次 2018年8月第1版 2018年8月第1次印刷

书号 ISBN 978-7-5603-7336-2

定价 98.00元

影印版说明

本手册由 Elsevier 授权影印出版。原版为全一册（共 19 章），考虑到内容的相对独立以及使用方便，影印版分为 6 册。

第 1 册 熔体·卷入·流动（第 1～3 章）。主要介绍金属熔体，包括熔体与周围环境可能发生的反应、熔体的流动性和可能存在的各种卷入性缺陷。

第 2 册 铸型和型芯·凝固组织·铸造合金（第 4～6 章）。第 4 章主要介绍铸型和型芯，包括铸型的性质、铸型和金属之间可能发生的反应。第 5、6 章主要介绍凝固组织的生长和可能存在的问题以及各种典型的铸造合金组织。

第 3 册 孔洞·热裂和冷裂·铸件的性能（第 7～9 章）。第 7、8 章主要介绍铸件中可能出现的缩孔和裂纹等缺陷。第 9 章主要介绍铸件的力学性能、抗氧化性能、耐腐蚀性能、密封性能以及表面处理。

第 4 册 获得优质铸件的 10 项准则（第 10 章）。

第 5 册 浇注系统设计基础、组成和设计实例（第 11～13 章）。主要介绍浇注系统的设计、组成，并给出浇注系统设计的实例分析。

第 6 册 熔炼·造型·铸造·凝固（第 14～19 章）。分别介绍铸造合金的熔炼、铸型材料和铸造成型方法的选择、凝固技术和铸件尺寸精度的控制、铸件的后续处理和探伤等。

本手册为从事铸造行业的科研人员和工程技术人员提供全面的指导和参考。目前国内尚没有如此完整介绍金属铸造工艺、冶金技术和设计、铸件质量控制和后续处理以及性能检测等方面的手册。

作者 John Campbell（约翰·坎贝尔）OBE，英国伯明翰大学（铸造专业）教授，铸件行业国际领先人物，Cosworth Casting 的创始人及 Baxi 铸造方法的发明人。

材料科学与工程图书工作室

联系电话 0451-86412421

0451-86414559

邮 箱 44739812@qq.com

zhxh6414559@aliyun.com

yh_bj@aliyun.com

Complete Casting Handbook

Metal Casting Processes, Metallurgy, Techniques and Design

Second Edition

John Campbell

*Emeritus Professor of Casting Technology,
Department of Metallurgy and Materials,
University of Birmingham, UK*



ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Butterworth-Heinemann is an imprint of Elsevier



Preface

In this first update of the *Handbook*, the major revisions are probably those relating to running system design in which the vestiges of filling defects have finally been eliminated from castings.

Thus, the powerful benefits of contact pouring (in which the universal conical trumpet decorating all traditional filling systems is now eliminated) is finally shown to have been hugely underestimated by a number of foundries. Contact pouring has probably been the most important (and the most simple and zero-cost) initiative to revolutionise quality in castings. In addition, the adoption of various forms of tangential filter designs to gates has finally eliminated the problem of the entrainment of priming bubbles. These residual bubbles have long impaired the benefits of previous filling systems.

Gravity pouring has now advanced to the point at which I find myself having to admit that it starts to threaten my cherished and favoured casting production system: countergravity.

This is seen to be especially true for those low-pressure systems which use a refractory lining for the pressurised furnace. I only recently discovered the hugely damaging emission of bubbles from these linings during depressurisation of the furnace. This problem has clearly been a major source of impaired castings in the low-pressure casting industry and has hampered this industry since its beginnings.

The use of my pneumatic pump is described for the first time. It would lower costs and solve most of the problems of this industry. Thus, I continue to stand by countergravity as the optimum casting system where it can be used. My hope is that it will be teamed up with a good melting and metal handling system. Only careful foundry design will minimise bifilm populations in metals. Only when castings can be produced substantially free from bifilms will we enjoy the full benefits of castings, and metals in general, resistant to hot tearing, cracking, blisters, corrosion pitting and attack of grain boundaries, plus the benefits of extraordinary mechanical properties, potentially eliminating future failure by fracture or fatigue.

These are heady predictions. However, early results in foundries are already indicating that beautiful defect-free castings with revolutionary metallurgical benefits appear to be routinely attainable. Despite challenges from the undoubtedly unique benefits of such new processes as additive manufacture, my hope for the future for castings is based on the adoption of simple principles which could not only secure the future of our casting industry, but improve the welfare and environment of all of us whose lives depend on it.

JC
Ledbury, Herefordshire, England
02 April 2015

Introduction

CASTINGS HANDBOOK, 2ND EDITION, 2015

When *Castings Handbook* first appeared in 2011, I had not expected to revise it so soon. However, the latest findings require publicising as quickly as possible—there is still a long way for the industry to go! The message of the book, summarised in the section “Bifilm-free Properties”, is that a quality improvement of astonishing scale is possible now. When I first started to experiment with novel filling systems for castings, there were naturally many disappointments. However, those days are long gone. The concepts of entrainment and bifilm creation laid out in the book are now proven. Some foundries are already being designed to take advantage of a unique and easily affordable quality revolution and scrap reduction. More need to follow. The risks are minimal and the rewards are great.

With regard to improved casting techniques which can reduce or even eliminate the usual vast populations of bifilms in our metals, I have always been aware of the potential benefit of contact pouring, but had completely underestimated its effects. It achieves miraculous improvements to castings by eliminating the 50% air mixing step. Contact pouring is strongly recommended in this volume as a major but low-cost step forward.

The ultimate step forward is countergravity casting which should always be targeted if possible. However, although I discuss the traditional pumping techniques, I present here for the first time my new pneumatic pump. It is another low-cost, reliable technique which enjoys uniquely low turbulence and might allow a rapid takeup of this unique technology.

Turning to the seriousness of the current position in casting, and in metallurgical engineering as a whole, the fact that most current metals can fail by cracking should alert us to the glaring inconsistency in our metallurgical thinking because many of our metals and alloys are ductile, so failure by cracking should be impossible. In a ductile metal an attempt to propagate a crack should merely result in the crack tip blunting, preventing propagation.

In the absence of any other viable alternative mechanism, that metals do crack is a strong indication that cracks pre-exist in metals in the form of bifilms formed in the liquid state during pouring of the metal to make a casting. The poor practice is almost universally associated with pouring methods which ensure that the molten metal is mixed and emulsified with at least 50 volume % of air during its journey into the mould. I defy anyone to make a respectable casting from such a disgracefully inappropriate and inept technique. This book presents the case that this need not be so; metals need not contain bifilms, and thus need not contain those Griffith cracks which can initiate failure by cracking. To achieve this, we simply have to improve our casting technology.

It remains the case that bifilms are still lamentably researched, so that this book has to resort to sifting through inconclusive and fragmentary evidence from researchers who were not looking for bifilms. Unfortunately, researchers up until now have not been aware of their presence, and certainly did not suspect their overwhelming influence on their results. Although a welcome start is being made by a few workers, I remain impatient for more definitive research to be carried out.

In the meantime, while researchers slowly get around to proving the background theory, founders need not wait for answers. Practical low bifilm casting techniques have already been developed and are described here. They promise the quality improvement and cost reduction that the casting industry so badly needs.

Acknowledgements

It is a pleasure to acknowledge the significant help and encouragement I have received from many good friends. John Grassi has been my close friend and associate at Alotech, the company promoting the new, exciting ablation castings process. Ken Harris has been an inexhaustible source of knowledge on silicate binders, aggregates and recycling. His assistance is clear in Chapter 15. Clearly, the casting industry needs more chemists like him. Bob Puhakka has been the first regular user of my casting recommendations for the production of large aluminium and steel castings, which has provided me with inspirational confirmation of the soundness of the technology described in this book. In addition, the practical feedback and warm friendship over several years from those at the UK steel foundry Furniss and White is a pleasure to record. Murat Tiryakioglu has been a loyal supporter and critic, and provides the elegantly written publications that have provided welcome scientific underpinning. He has provided generous and invaluable help with the important section *The Statistics of Failure*. Naturally, many other acknowledgements are deserved among friends and students whose research has been a privilege to supervise. I do not take these for granted. Even if not listed here, they are not forgotten.

The American Foundry Society is thanked for the use of a number of illustrations from *Transactions*.

目 录

前言.....	xxv
引言.....	xxvi
致谢.....	xxvii

铸造冶金学

第1册(本册) 熔体·卷入·流动(第1~3章)

第1章 熔体.....	3
1.1 熔体与环境的反应.....	5
1.2 气体在熔体中的传输.....	9
1.3 表面膜的形成.....	11
1.4 蒸发.....	14
第2章 卷入.....	17
2.1 卷入性缺陷.....	21
2.2 卷入过程.....	37
2.3 卷曲和展开.....	67
2.4 卷入膜的惰性化.....	77
2.5 可溶性瞬态膜.....	80
2.6 卷出过程.....	81
2.7 双层膜的证据.....	83
2.8 双层膜的重要性.....	88
2.9 四种常见的双层膜.....	89
第3章 流动.....	91
3.1 表面膜对填充的影响.....	91

3.2 最大流动性.....	95
3.3 延长流动性.....	128
3.4 连续流动性.....	131

第2册 铸型和型芯·凝固组织·铸造合金（第4~6章）

第4章 铸型和型芯.....	135
4.1 惰性铸型和活性铸型	135
4.2 传质区.....	136
4.3 蒸发区和凝聚区.....	139
4.4 铸型气氛.....	144
4.5 铸型表面反应.....	147
4.6 金属表面反应.....	155
4.7 铸型涂层.....	159
第5章 凝固组织.....	163
5.1 传热.....	163
5.2 基体组织的生长.....	197
5.3 偏析.....	213
第6章 铸造合金.....	223
6.1 锌合金.....	223
6.2 镁合金.....	227
6.3 铝合金.....	236
6.4 铜合金.....	269
6.5 铸铁.....	275
6.6 钢.....	314
6.7 镍基合金.....	330
6.8 钛合金.....	335

第3册 孔洞·热裂和冷裂·铸件的性能（第7~9章）

第7章 孔洞.....	341
7.1 收缩.....	341
7.2 气孔.....	387

7.3 孔洞的识别.....	413
第8章 热裂和冷裂.....	417
8.1 热裂.....	417
8.2 冷裂.....	442
第9章 铸件的性能.....	447
9.1 试棒.....	447
9.2 失效统计.....	450
9.3 缺陷的影响.....	463
9.4 拉伸性能.....	470
9.5 断裂韧性.....	493
9.6 疲劳性能.....	498
9.7 弹性(杨氏)模量和阻尼性能.....	507
9.8 残余应力.....	508
9.9 高温拉伸性能.....	509
9.10 抗氧化和耐腐蚀性能.....	511
9.11 密封性.....	519
9.12 表面处理.....	523
9.13 质量指数.....	526
9.14 无双层膜时性能.....	527

铸件制造(生产)

第4册 获得优质铸件的10项准则(第10章)

铸件制造业概论.....	529
--------------	-----

第一部分 获得优质铸件的准则

第10章 获得优质铸件的10项准则.....	535
10.1 准则1:从高质量的熔体开始.....	536
10.2 准则2:避免液面湍流夹杂.....	542
10.3 准则3:避免液面层状夹杂.....	550

10.4	准则 4: 避免裹气.....	557
10.5	准则 5: 避免砂芯气孔.....	561
10.6	准则 6: 避免缩孔.....	573
10.7	准则 7: 避免对流.....	603
10.8	准则 8: 减少偏析.....	610
10.9	准则 9: 减少残余应力.....	613
10.10	准则 10: 给定基准点.....	631

第 5 册 浇注系统设计基础、组成和设计实例 (第 11 ~ 13 章)

第二部分 浇注系统设计

第 11 章	浇注系统设计基础.....	641
11.1	最大充型速度要求.....	642
11.2	重力浇注.....	642
11.3	降低和排除重力浇注问题.....	646
11.4	表面张力控制下的充型.....	651
第 12 章	浇注系统组成.....	657
12.1	浇口杯.....	657
12.2	直浇道.....	669
12.3	横浇道.....	683
12.4	内浇道.....	690
12.5	液流缓冲单元.....	716
12.6	防涡流单元.....	719
12.7	夹杂物的控制: 过滤和集渣.....	724
12.8	过滤器.....	728
第 13 章	浇注系统设计实例.....	747
13.1	设计方案.....	748
13.2	浇注方案的确定.....	748
13.3	质量和体积的估计.....	748
13.4	封闭式和开放式.....	750
13.5	浇注时间的选择.....	755
13.6	薄壁件和缓慢充型.....	758

13.7 充型速度.....	758
13.8 浇口杯的设计.....	759
13.9 直浇道的设计.....	759
13.10 横浇道的设计.....	763
13.11 内浇道的设计.....	765

第6册 熔炼·造型·铸造·凝固 (第14 ~ 19章)

第三部分 生产过程 (熔炼、造型、铸造、凝固)

第14章 熔 炼.....	769
14.1 间歇式熔炼.....	769
14.2 连续熔炼.....	772
14.3 保温、转运和分配.....	774
14.4 熔体处理.....	777
14.5 铸造材料.....	790
14.6 重熔.....	794
第15章 造 型	797
15.1 惰性铸型和铸芯.....	797
15.2 原砂.....	802
15.3 黏结剂.....	807
15.4 其他造型方法.....	813
15.5 橡胶铸型.....	814
15.6 原砂的回收和循环.....	814
第16章 铸 造.....	821
16.1 重力铸造.....	821
16.2 水平铸造.....	827
16.3 反重力铸造.....	838
16.4 离心铸造.....	856
16.5 压力辅助铸造.....	861
16.6 熔膜铸造和其他陶瓷型铸造工艺.....	871
16.7 消失模铸造.....	875

16.8	真空铸造	878
16.9	真空加压铸造	880
16.10	真空熔炼和铸造	881
第 17 章	凝固控制技术	883
17.1	常规凝固	883
17.2	定向凝固	883
17.3	单晶体凝固	885
17.4	快速凝固	887
第 18 章	尺寸精度	893
18.1	净成型概念	897
18.2	模样设计	900
18.3	模样精度	904
18.4	加工精度	909
18.5	铸造精度	910
18.6	测量技术	924
第 19 章	铸件处理	927
19.1	表面清理	927
19.2	热处理	929
19.3	热等静压	935
19.4	加工	938
19.5	上漆	940
19.6	塑性加工(锻、轧、挤压)	941
19.7	浸渗	942
19.8	无损检测	942
附录 I		947
附录 II		951
附录 III		955
附录 IV		957
参考文献		959
索引		993

Contents

Preface	xxv
Introduction.....	xxvi
Acknowledgements.....	xxvii

CASTING METALLURGY

第 1 册 (本册) 熔体 · 卷入 · 流动 (第 1 ~ 3 章)

CHAPTER 1 The Melt	3
1.1 Reactions of the Melt with its Environment	5
1.2 Transport of Gases in Melts	9
1.3 Surface Film Formation.....	11
1.4 Vaporisation	14
CHAPTER 2 Entrainment	17
2.1 Entrainment Defects	21
2.1.1 Bifilms	21
2.1.2 Bubbles	25
2.1.3 Extrinsic Inclusions	30
2.2 Entrainment Processes	37
2.2.1 Surface Turbulence.....	37
2.2.2 Oxide Skins from Melt Charge Materials.....	46
2.2.3 Pouring.....	47
2.2.4 The Oxide Lap Defect I: Surface Flooding.....	50
2.2.5 Oxide Lap Defect II: The Confluence Weld.....	52
2.2.6 The Oxide Flow Tube	56
2.2.7 Microjetting	57
2.2.8 Bubble Trails	58
2.3 Furling and Unfurling	67
2.4 Deactivation of Entrained Films.....	77
2.5 Soluble, Transient Films.....	80
2.6 Detrainment.....	81
2.7 Evidence for Bifilms.....	83
2.8 The Importance of Bifilms	88
2.9 The Four Common Populations of Bifilms	89
CHAPTER 3 Flow	91
3.1 Effect of Surface Films on Filling.....	91
3.1.1 Effective Surface Tension	91

3.1.2	The Rolling Wave.....	92
3.1.3	The Unzipping Wave.....	92
3.2	Maximum Fluidity (The Science of Unrestricted Flow)	95
	Fluidity Definition	96
3.2.1	Mode of Solidification.....	97
3.2.2	Effect of Velocity	110
3.2.3	Effect of Viscosity (Including Effect of Entrained Bifilms)	110
3.2.4	Effect of Solidification Time t_f	112
3.2.5	Effect of Surface Tension.....	121
3.2.6	Effect of an Unstable Substrate	124
3.2.7	Comparison of Fluidity Tests.....	125
3.2.8	Effect of Vibration.....	128
3.3	Extended Fluidity.....	128
3.4	Continuous Fluidity	131

第 2 册 铸型和型芯·凝固组织·铸造合金 (第 4 ~ 6 章)

CHAPTER 4	Moulds and Cores	135
4.1	Moulds: Inert or Reactive.....	135
4.2	Transformation Zones.....	136
4.3	Evaporation and Condensation Zones.....	139
4.4	Mould Atmosphere	144
4.4.1	Composition.....	144
4.4.2	Mould Gas Explosions	145
4.5	Mould Surface Reactions.....	147
4.5.1	Pyrolysis	147
4.5.2	Lustrous Carbon Film	148
4.5.3	Sand Reactions	149
4.5.4	Mould Contamination.....	149
4.5.5	Mould Penetration	151
4.6	Metal Surface Reactions.....	155
4.6.1	Oxidation	155
4.6.2	Carbon (Pickup and Loss).....	155
4.6.3	Nitrogen	156
4.6.4	Sulphur.....	157
4.6.5	Phosphorus.....	157
4.6.6	Surface Alloying.....	158
4.6.7	Grain Refinement	158
4.6.8	Miscellaneous	159
4.7	Mould Coatings.....	159
4.7.1	Aggregate Moulds	159
4.7.2	Permanent Moulds and Metal Chills	160
4.7.3	Dry Coatings.....	161

CHAPTER 5	Solidification Structure	163
5.1	Heat Transfer	163
5.1.1	Resistances to Heat Transfer	163
5.1.2	Increased Heat Transfer	178
5.1.3	Convection.....	193
5.1.4	Remelting.....	193
5.1.5	Flow Channel Structure.....	194
5.2	Development of Matrix Structure.....	197
5.2.1	General.....	197
5.2.2	Nucleation of the Solid	198
5.2.3	Growth of the Solid.....	201
5.2.4	Disintegration of the Solid (Grain Multiplication).....	209
5.3	Segregation.....	213
5.3.1	Planar Front Segregation.....	213
5.3.2	Microsegregation	216
5.3.3	Dendritic Segregation.....	218
5.3.4	Gravity Segregation.....	219
CHAPTER 6	Casting Alloys	223
6.1	Zinc Alloys	223
6.2	Magnesium Alloys.....	227
6.2.1	Films on Liquid Mg Alloys + Protective Atmospheres	228
6.2.2	Strengthening Mg Alloys	230
6.2.3	Microstructure	234
6.2.4	Inclusions.....	235
6.3	Aluminium	236
6.3.1	Oxide Films on Al Alloys.....	237
6.3.2	Entrained Inclusions	239
6.3.3	Grain Refinement (Nucleation and Growth of the Solid)	239
6.3.4	Dendrite Arm Spacing (DAS) and Grain Size	244
6.3.5	Modification of Eutectic Si in Al-Si Alloys	244
6.3.6	Iron-Rich Intermetallics	259
6.3.7	Other Intermetallics.....	262
6.3.8	Thermal Analysis of Al Alloys.....	264
6.3.9	Hydrogen in Al Alloys.....	267
6.4	Copper Alloys	269
6.4.1	Surface Films.....	270
6.4.2	Gases in Copper-Based Alloys	270
6.4.3	Grain Refinement	274