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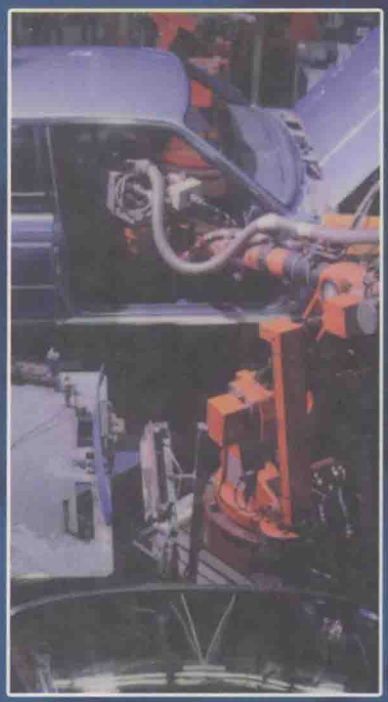
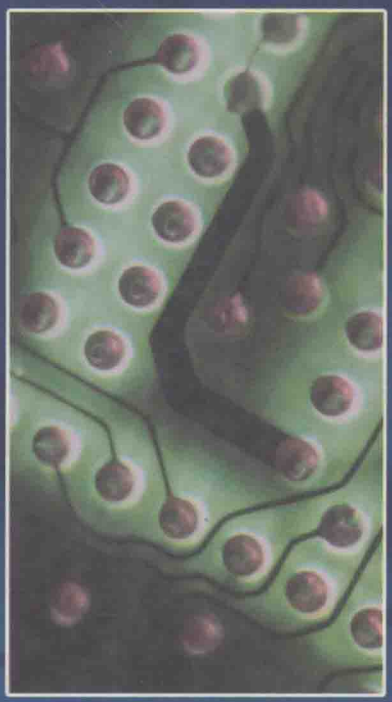
制造工程与技术(热加工)(英文版)及学习辅导（下册）

制造工程与技术(热加工)学习辅导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机械工业出版社
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下　册

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主编　全燕鸣
参编　袁　宁　高　岩

机械工业出版社

机械工业出版社的影印教材《Manufacturing Engineering and Technology — Hot Process》取自原版英文教材《Manufacturing Engineering and Technology》（PRENTICE HALL 2001，第4版，ISBN 0-201-36131-0）中的部分篇章。内容涵盖金属铸造工艺与设备、压力成形工艺与设备、连接工艺与设备、粉末冶金工艺与设备、非金属材料加工和快速成形工艺与设备。

《制造工程与技术（热加工）学习辅导》是为上述影印原版教材配套而编写的。内容为影印教材各章节目录、INTRODUCTION、SUMMARY、TRENDS和KEY TERMS的对照中文翻译以及各章中疑难句子的中文翻译。本书可作为机械工程类的本、专科学生学习英文原版教材的辅导，也可随原版教材一起作为工程技术人员的参考资料及涉外企业员工的培训教材。

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前　言

按照教育部高校教材建设的发展规划，本科院校，尤其是重点院校，部分课程逐步采用外语教学和外文教材已是势在必行，许多学校正在计划让一部分基础课和主干专业课在这方面先行一步。考虑到外语教学对教师和学生都必须有一个循序渐进的过程，目前大多数院校的师资和生源达不到直接使用原版外文教材并同时用外语授课的水平，故编写和使用英汉双语教材，视教师和生源情况灵活采用双语授课不失为当前适应形势发展需要的好办法。

许多学校的机械学院（系）都已经按大专业招生，砍去原先的小专业和小专业课程。“材料成形基础”和“机械制造工程学”是按机械工程大学科专业招生后本科生的主干专业课程，所用的是为适应教学体系改革而编写的综合性教材。“材料成形基础”涵盖了原先铸造、压力加工、焊接三个专业的原理、工艺、设备等多门课程的主要内容；“机械制造工程学”由原先机械制造专业的“机械制造工艺学”、“金属切削原理”、“金属切削刀具”、“机床概论”、“夹具设计”、“机床设计”等6门课程整合而成。近年陆续有类似教材面世，但都是中文版。几年来这些讲义（书）已为历届学生所使用并收到了一定效果，但是随着形势的发展和改革的深入，也逐渐出现了一些亟待解决的问题：

1. 制造技术日新月异，特别是近年来，以计算机、信息技术为代表的高新技术的发展，使制造技术的内涵和外延发生了革命性的变化。作为培养高层次人才所用的大学教材理所当然地应该及时反映这些发展。但是现用讲义内容已显陈旧，即便是国内新出版的同类教材，其取材也基本上还是来自旧教材，虽有点滴新技术介绍，也比国外教材慢了若干节拍。因此，该课程所用教材急需更新，而直接引进国外同类新教材是解决此问题的好途径。

2. 对于现在要拓宽学生适应面，培养复合型人才的教学计划安排而言，授课学时不够是各校都头痛的问题。各校近年虽然都在强调外语教学的重要性，除公共外语以外，都还开设专业外语课程，但苦于课时不够安排，专业外语课时只好被一再压缩。实际上学生学习专业外语的时间太少，以致于毕业找工作时常因此抱憾。而机械类大专业学生的专业外语教材主要内容正是“材料成形基础”和“机械制造工程学”所涵盖的范围。如果这两门课程使用外语或双语教学，完全可以将其与专业外语课程合并，这样既利于课时安排，又提高了学生的专业外语水平。

原版英文教材《Manufacturing Engineering and Technology》（Copyright 2001，1148pp，ISBN 0-201-36131-0，Serope Kalpakjian，Steven R. Schmid，The University Of Nitre Dame）是全球最大的教育出版集团 PRENTICE HALL 2001 年最新出版的第4版本科生教材，被许多国家著名院校广为采用作为机械工程类本科生的教科书。该书共有40章，长达1148页，幅面为260mm×210mm，内容涵盖工程材料、机加工、热加工、特种加工、表面工程和先进制造技术。此原版教材引入中国尚属首次，机械工业出版社获得其影印版权。考虑到原书篇幅太长，而我国院校教学计划中尚难设置太长的课时来开设这门课程，并且我国学生也难以为一本书支付太高价格，经原作者和原出版社同意，现将其中铸造工艺与设备（第10～12章）、压力成形工艺与设备（第13～16章）、金属冶金及陶瓷、玻璃和超导体加工工艺（第17章）、塑料与复

合材料成形（第18章）、快速成形工艺（第19章）和连接工艺与设备（第27～30章）取出，合成《制造工程与技术（热加工）》影印出版；将其中金属去除工艺与机床（第20～25章）、先进加工方法和纳米制造（第26章）、制造工艺过程自动化（第38章）、计算机集成制造系统（第39章）和制造的竞争环境（第40章）取出，合成《制造工程与技术（机加工）》影印出版；另外配套编写对应的学习辅导随同影印书出版发行。学习辅导的内容包括：对照翻译了原版书上述各章的目录、简介（INTRODUCTION）、小结（SUMMARY）、发展趋势（TRENDS）和关键术语（KEY TERMS），另外摘取各章中的疑难句子作了注释。

《制造工程与技术（热加工）》、《制造工程与技术（机加工）》教材的主要应用对象是机械工程类的本、专科学生，各校可根据自身需要和实际课时灵活选用授课内容和双语形式。这两本书也可作为工程技术人员的参考书及涉外企业员工作培训教材。

随同这两本英文影印教材出版的两本学习辅导由华南理工大学机械学院的教师编写，其中《制造工程与技术（热加工）学习辅导》的第一篇由全燕鸣编写，第二篇由袁宁和全燕鸣编写，第三篇由高岩编写；《制造工程与技术（机加工）学习辅导》第一篇的第20章由全燕鸣、刘旺玉编写，第21和25章由陈秉均编写，第22和24章由林颖编写，第23章和26章由刘旺玉编写，第二篇由全燕鸣编写。两本学习辅导书均由全燕鸣主编。

采用外文原版教材进行双语教学是一种教学改革，为此编写学习辅导也是一种尝试。由于编者的水平和时间所限，书中难免有谬误之处，敬请读者批评指正。

编　者

2003年10月于广州

目　　录

Part II Metal-Casting Processes and Equipment
第一篇（原版 Part II） 金属铸造工艺与设备

Chapter 10 Fundamentals of Metal-Casting
第 10 章 金属铸造基础

INTRODUCTION 简介

The casting process basically involves (a) pouring molten metal into a mold patterned after the part to be manufactured, (b) allowing it to cool, and (c) removing the metal from the mold. As with all other manufacturing processes, an understanding of the fundamentals is essential—both for the production of good quality and economical castings, and to establish proper techniques for mold design and casting practice.

铸造工艺基本上包括 (a) 把金属液浇注到用模样成型了的型腔中；(b) 使其冷却；(c) 从型中取出铸件。如同对所有其他制造工艺方法一样，应该从获得良好质量而又经济的铸件，到确定合适的型腔设计和铸造工艺两方面理解其基本原理的实质。

Important considerations in casting operations are as follows:

铸造操作中需着重考虑以下方面：

- the flow of the molten metal into the mold cavity;
  金属液流进型腔；
- the solidification and cooling of the metal in the mold;
  金属在型腔中凝固和冷却；
- the influence of the type of mold material.
  造型材料类型的影响。

This chapter describes the relationship among the many factors involved in casting. The flow of molten metals into the mold cavity is discussed in terms of mold design and fluid flow characteristics. Solidification and cooling of metals in the mold are affected by several factors, including the metallurgical and thermal properties of the metal. The type of mold has an important influence because it affects the rate of cooling of the metal in the mold. Factors influencing defect formation are also described.

本章讲述铸造中所牵涉许多因素之间的联系。根据铸型设计和液体流动特性来讨论金属液充填型腔。金属在型腔中的凝固和冷却受多个因素的影响，包括金属的冶金和热特性。铸型类型有重要影响，因为它影响金属在铸型中的冷却率。也将讨论影响缺陷形成的因素。

Industrial metal casting processes, design considerations, and casting materials are described in Chapter 11 and 12. The casting of ceramics and of plastics, which involves similar methods and procedures, are described in Chapter 17 and 18, respectively.

第 11 和 12 章讲述工业金属铸造工艺、铸件设计和铸造材料。陶瓷和塑料的铸造涉及类似的方法和工序，将分别在第 17 和 18 章中讲述。

SUMMARY 小结

- Casting is a solidification process in which molten metal is poured into a mold and allowed to cool. The metal may flow through a variety of passages (including pouring basins, sprues, runners, risers, and gating systems) before reaching the final mold cavity. Bernoulli's theorem, the continuity law, and the Reynolds number are the analytical tools used in designing, with the goals of an appropriate flow rate and the elimination of defects associated with fluid flow.

铸造是一种凝固工艺方法。这种工艺方法是将熔化了的金属液浇注到铸型中并使之冷却。金属液可能流经各种通道（包括浇口池、直浇道、横浇道、冒口和内浇口）才到达最终型腔。利用柏努利定律、连续性定理和雷诺数作为设计中的分析工具，以达到适当的流速流量，消除因流体流动不足而引起的缺陷。

- Solidification of pure metals takes place at a constant temperature; solidification of alloys occurs over a range of temperatures, depending on composition. Phase diagrams are important tools for identifying the solidification point or points for technologically important materials.

纯金属在确定的温度发生凝固，而合金的凝固在一个温度区间进行。相图是用于确定工艺材料凝固点的重要工具。

- Composition and cooling rates of the melt affect the size and shape of grains and dendrites in the solidified casting. Solidification time is a function of the volume of a casting and its surface area (Chvorinov's rule).

金属成分和冷却速率影响铸件凝固后晶粒和枝晶的大小和形状。凝固时间是铸件体积大小和其表面积的函数（契维瑞诺夫定则）。

- The grain structure of castings can be controlled by various means to obtain the desired properties. Because metals contract during solidification and cooling, cavities can form in the casting. Porosity caused by gases evolved during solidification can be a significant problem, particularly because of its adverse effect on the mechanical properties of the castings. Various defects can develop in castings from lack of control of material and process variables.

可通过各种方法对铸件的晶粒组织进行控制以获得所期望的性能。因为金属在凝固和冷却期间与型腔相接触，所以型腔能够成形铸件。凝固期间所析出气体引起的气孔是个严重问题，特别因其对铸件力学性能有不利影响。也可能由于缺乏对材料和工艺变量的有效控制而在铸件中产生各种缺陷。

- Although most metals shrink during solidification, gray cast iron and some aluminum alloys actually

expand. Dimensional changes and cracking (hot tearing) and difficulties which can arise during solidification and cooling. Seven basic categories of casting defects have been identified.

虽然大多数金属在凝固期间产生收缩，但灰铸铁和某些铝合金却可能发生膨胀。在凝固和冷却期间可能发生尺寸变化和裂纹（热撕裂）以及其它问题。已鉴别出的铸件缺陷有七类。

● Melting practices have a direct effect on the quality of castings, as do foundry operations such as pattern and mold making, pouring of the melt, removal of cast parts from molds, cleaning, heat treatment, and inspection.

熔炼操作对铸件质量有直接影响，铸造操作也是这样，例如模样和铸型制作、金属液浇注、铸件出型和清理、热处理、检验等环节。

TRENDS 发展趋势

● Argon-oxygen decarburization and deoxidation, as well as electroslag remelting, ladle metallurgy, plasma refining, and calcium wire injection for the production of high-quality steels, are now being practiced by modern foundries.

氩—氧脱碳和还原，以及电渣重熔、浇包冶金、等离子精练和钙丝注入等，正在现代铸造厂用于优质钢生产。

● Investigation of the following is underway: electromagnetic stirring of the molten metal in the mold and vibration of the mold to obtain smaller and more uniform grain size during solidification; counter-gravity pouring; and shrouding the pouring stream.

下列调查研究正在进行中：凝固期间电磁搅拌铸型中的金属液和振动铸型以获得比较小和均匀的晶粒组织；反重力浇注；屏蔽浇注液流。

● Computer-aided design and manufacturing techniques are being used to predict solodificatioo patterns, prevent casting defects, and calculate weights, volumes, and dimensions for proper mold design and economical production.

为获得正确的铸型设计和经济地生产铸件，计算机辅助设计和制造技术正被用于预报凝固模式，防止铸件缺陷，计算重量、体积和尺寸等。

● Improvements in the efficiency of furnaces, molten metal quality, and purifying and filtering techniques are being made.

正在开发应用提高熔炉效率和金属液质量、净化和过滤等技术工艺。

KEY TERMS 关键术语

Aspiration ［真空］抽吸
Bernoulli's theorem 柏努利定律
Casting 铸件，铸造
Chills 金属型，激冷铸型，冷铁，白口层，激冷
Columnar dendrites 柱状枝晶
Columnar grains 柱状晶
Cored dendrites 芯部枝晶

Dendrites　枝晶
Fluidity　流动性
Freezing range　凝固区间，凝固范围
Gate　浇口，浇注系统，内浇口，闸门
Gating system　浇注系统
Heterogeneous nucleation　异质结核，多相成核
Homogenous nucleation　均质结核，单相成核
Inoculant　孕育剂，变质剂（有色）
Macrosegregation　宏观偏析
Microsegregation　微观偏析
Mold　铸型，锭模
Mushy zone　固—液相混合区，糊状区
Porosity　气孔率，孔隙度，缩松
Pouring basin　池形外浇口
Reynolds number　雷诺数
Risers　冒口
Runners　横浇口，流槽
Segregation　偏析
Shrinkage　收缩，缩孔
Skin　铸皮，表皮层
Solidification　凝固
Sprue　直浇口
Turbulence　湍流，紊流

疑难句子注释

1. After molten metal is poured into a mold, a series of events takes place during the solidification of the casting and its cooling to ambient temperature. These events greatly influence the size, shape, uniformity, and chemical composition of the grains formed throughout the casting, which in turn influence its overall properties.

（P242 第 1 段第 1 行）金属液被浇进铸型后，在其凝固及冷却至室温的过程中会发生一系列变化。这些变化对整个铸件晶粒的大小、形状、均匀性和化学成分影响很大，而这些又依次影响铸件总的性能。

2. After the temperature of the molten metal drops to its freezing point, its temperature remains constant while the latent heat of fusion is given off. The solidification front (solid-liquid interface) moves through the molten metal, solidifying from the mold walls in toward the center. Once solidification has taken place at any point, cooling resumes. The solidified metal, called the casting, is taken out of the mold and is allowed to cool to ambient temperature.

（P242 第 3 段第 1 行）当金属液的温度下降到其凝固点，其温度保持恒定而放出结晶潜热。凝固前沿（固—液界面）通过金属液移动，凝固从铸型壁开始向心部发展。一旦各处都

发生凝固，冷却就会重新进行。已凝固的金属称作铸件，它被从铸型中取出并继续冷却至室温。

3. As the driving force of the heat transfer is reduced away from the mold walls, the grains become equiaxed and coarse. Those grains that have substantially different orientations are blocked from further growth. Such grain development is known as homogenous nucleation, meaning that the grains (crystals) grow upon themselves, starting at the mold wall.

(P243 第 2 段第 1 行) 随着至型壁的距离加大，热迁移驱动力减弱，晶粒变成粗大等轴晶。那些有明显不同取向的晶粒的进一步生长受到限制。这样的晶粒生长被称为均匀成核，意指晶粒靠自身生长，始发于型壁。

4. Note the presence of liquid metal between the dendrite arms. Dendrites have three-dimensional arms and branches (secondary arms) which eventually interlock, as can be seen in Fig. 10.4. The study of dendritic structures although complex, is important because such structures contribute to detrimental factors such as compositional variations, segregation, and microporosity.

(P244 第 2 段第 1 行) 注意树晶枝之间存在的金属液。树枝晶有三维晶枝以及分枝 (二次晶枝)，它们最终会交叉互锁，如图 10.4 中所示。尽管对树枝晶结构的研究是复杂的，但这是重要的，因为这样的结构对于诸如成分变化、偏析和微孔等起有害作用。

5. Because of the presence of thermal gradients in a solidifying mass of liquid metal, and because of gravity and the resultant density differences, convection has a strong influence on the structures developed. Convection promotes the formation of an outer chill zone; refines grain size; and accelerates the transition from columnar to equiaxed grains. The structure shown in Fig. 10.5b can also be obtained by increasing convection within the liquid metal, whereby dendrite arms separate (dendrite multiplication). Conversely, reducing or eliminating convection results in coarser and longer columnar dendritic grains.

(P246 第 6 段第 1 行) 由于在液态金属凝固范围里存在热梯度，还存在重力和因之而产生的密度差异，所以强烈的对流作用会影响所产生的组织结构。对流有助于形成外激冷区，细化晶粒，促进柱状晶向等轴晶转化。图 10.5b 中所示的结构也可以通过增强液态金属中的对流而获得，凭借此作用而使晶枝分离 (枝晶增殖)。因此，减少或消除对流会导致粗大而长的柱状枝晶。

6. Recall that in a free-falling liquid (such as water from a faucet) the cross-section area of the stream decreases as it gains velocity downward. If we design a sprue with a constant cross-section area and pour the molten metal into it, regions may develop where the liquid loss contact with the sprye walls. As a result aspiration, a process whereby air is sucked in or entrapped in the liquid, may take place. On the other hand, tapered sprues are now replaced in many systems by straight-sided sprues with a choke to allow the metal to flow smoothly.

(P248 第 4 段第 1 行) 回想自由落下的水流 (例如从水龙头流下的水)，其横截面积随其获得的向下速度而减小。如果我们设计一个截面积不变的直浇道并向其浇注金属液，可能会出现液流接触不到浇道壁的区域。由于有吸气作用，在浇注过程中可能卷入空气。另一方面，锥形的直浇道现在在许多系统中被带节流口的平直直浇道所取代，以使金属液平稳地流动。

7. Techniques for minimizing turbulence generally involve avoidance of sudden changes in flow direction and in the geometry of channel cross-sections in gating system design.

(P248 末段第 6 行) 使紊流最小化的技巧一般是在浇口系统设计中注意避免流动方向和浇道截面积突然改变。

8. Although heating the mold improves fluidity, it slows down solidification of the metal and the casting develops coarse grains and hence has lower strength.

(P249 倒数第 5 段第 3 行) 虽然加热能改善流动性，但是减缓了金属的凝固，导致铸件产生粗大晶粒，因而使强度降低。

9. During the early stages of solidification, a thin, solidified skin begins to form at the cool mold walls and, as time passes, the skin thickens (Fig.10.10). With flat mold walls, this thickness is proportional to the square root of time. Therefore, doubling the time will make the skin $\sqrt{2} = 1.41$ times, or 41%, thicker.

(P250 倒数第 2 段第 1 行) 在凝固早期，在冷的铸型壁上形成凝固的薄表层；随着时间推移，此表层增厚 (图 10.10)。如果型壁平直，此厚度正比于时间的平方根值。因此，加倍的时间将使得此表层增厚 1.41 倍，即增厚 41%。

10. Cold shut is an interface in a casting that lacks complete fusion because of the meeting of two streams of liquid metal from different gates.

(P254 第 1 段第 5 行) 冷隔是铸件上由于从不同浇口流入的金属液流相遇时未能完全熔合而产生的界面。

11. Whether microporosity is a result of shrinkage or is caused by gases may be difficult to determine. If the porosity is spherical and has smooth walls (much like the shiny holes in Swiss cheese), it is generally from gases. If the walls are rough and angular, porosity is likely from shrinkage between dendrites. Gross porosity is from shrinkage and is usually called a shrinkage cavity.

(P256 第 2 段第 1 行) 显微疏松是因收缩所致还是由于存在气体所致可能难以确定。如果孔洞是球形的并且壁面光滑 (很象瑞士硬干酪里的光亮孔)，通常它是因气体的缘故。如果孔壁粗糙而为多角形，这样的孔洞很可能是因枝晶间收缩的缘故。粗大孔是因收缩所致，通常称为缩孔。

Chapter 11 Metal-Casting Processes
第 11 章 金属铸造工艺

INTRODUCTION 简介

The first castings were made during the period 4000-3000B.C., using stone and metal molds for casting copper. Various casting processes have been developed over a long period of time, each with its own characteristics and applications to meet specific engineering and service requirements (Table 11.1). Many parts and components are made by casting, including cameras (Fig.11.1), carburetors, engine blocks, crankshafts, automotive components (Fig.11.2), agricultural and railroad equipment, pipes and plumbing fixtures, power tools, gun barrels, frying pans, and very large components for hydraulic turbines (Fig.11.3).

最早的铸件是在公元前 3000—4000 年用石头和金属型做出来的铜器。在漫长的时期中发展出了各种各样的铸造工艺方法，每种工艺方法都有其自己的特性和用途，以满足特定的工程与服务需求（表 11.1）。许多零件和构件都是用铸造法生产的，包括照相机（图 11.1）、汽化器、发动机体、曲轴、汽车构件（图 11.2）、农业和铁路设备、管道和管子附件、电动工具、枪炮管、煎锅，还有巨大的水轮机构件（图 11.3）。

TABLE 11.1 Summary of Casting Processes, Their Advantages and Limitations

Process	Advantages	Limitations
Sand	Almost any metal cast; no limit to size, shape or weight; low tooling cost.	Some finishing required; somewhat coarse finish; wide tolerances.
Shell mold	Good dimensional accuracy and surface finish; high production rate.	Part size limited; expensive patterns and equipment required.
Expendable pattern	Most metals cast with no limit to size; complex shape.	Patterns have low strength and can be costly for low quantities.
Plaster mold	Intricate shapes; good dimensional accuracy and finish; low porosity.	Limited to nonferrous metals; limited size and volume of production; mold making time relatively long.
Ceramic mold	Intricate shapes; close tolerance parts; good surface finish.	Limited size.
Investment	Intricate shapes; excellent surface finish and accuracy; almost any metal cast.	Part size limited; expensive patterns, mold, and labor.
Permanent mold	Good surface finish and dimensional accuracy; low porosity; high production rate.	High mold cost; limited shape and intricacy; not suitable for high-melting point metals.
Die	Excellent dimensional accuracy and surface finish; high production rate.	Die cost is high; part size limited; usually limited to nonferrous metals; long lead time.
Centrifugal	Large cylindrical parts with good quality; high production rate.	Equipment is expensive; part shape limited.

表 11.1 铸造工艺总概、各种工艺的优点和限制

工 艺	优 点	限 制
砂型	几乎适合于任何金属铸造；不受尺寸、形状或重量的限制；工装成本低	需要一定的修整；表面稍粗糙；公差范围宽
壳型	铸件有良好的尺寸精度，表面光洁；生产率高	零件尺寸受限；模样和设备费大
一次性模	对大多数金属铸造无尺寸限制；适于形状复杂的铸件	模样强度低，对少量铸件生产而言模样费用昂贵
石膏型	适于形状复杂的铸件；铸件尺寸精度高，表面光洁；气孔率低	限于非铁金属铸造；铸件尺寸和产量受限；造型时间相对长
陶瓷型	适于形状复杂、公差小的铸件；铸件表面光洁	铸件尺寸受限制
熔模铸造	适于形状复杂的铸件；铸件有优异的光洁表面和精度；几乎适于任何金属铸造	铸件尺寸有限；模样、铸型和劳动力费用大
永久型	铸件有光洁表面和良好的尺寸精度；气孔率低；生产率高	铸型费用大；铸件形状和复杂性受限；不适于高熔点金属铸造
压铸	铸件尺寸精度很高，表面很光洁；生产率高	模具成本高；铸件尺寸受限；通常只限于非铁金属铸造；订货至交货的准备时间长
离心铸造	适于大的空心圆柱零件铸造，质量高；生产率高	设备费用大；零件形状受限

FIGURE 11.1 (a) The Polaroid PDC-2000 digital camera with a AZ91D die-cast, high-purity magnesium cast. (b) Two-piece Polaroid camera case made by the hot-chamber die casting process. Source: Courtesy of Polaroid Corporation and Chivago Withte Metal Casting, Inc.

图 11.1（a） Polaroid PDC-200 数字照相机壳体，用 AZ91D 材料压铸的高纯度镁铸件。(b) 两片由热室压铸工艺生产的 Polaroid 照相机壳体。资料来源：Polaroid 公司和 Chivago Withte 金属铸件公司

FIGURE 11.2 Typical gray-iron castings used in automobiles, including transmission valve body (left) and hub rotor with disk-brake cylinder (front). Source: Courtesy of Central Foundry Division of General Motors Corporation.

图 11.2 使用在汽车上的典型灰铸铁件，包括变速阀体（左）和轮毂转子（前）。资料来源：通用电动机公司中心铸造部

FIGURE 11.3 A cast transmission housing.

图 11.3 一个铸造的变速箱体

Two trends are currently having a major impact on the casting industry. The first is continuing mechanization and automation of the casting process, which has led to significant changes in the use of equipment and labor. Advanced machinery and automated process-control systems have replaced traditional methods of casting. The second major trend is the increasing demand for high-quality casting with close dimensional tolerances and no defects (Table 11.2).

当前有两个趋势对铸造工业起主要冲击作用。第一个是正在继续进行的铸造过程机械化和自动化，它导致铸造设备和劳动力方面发生重大变化。先进的机械和自动的过程控制系统已经取代了传统的铸造方法。第二个主要趋势是对具有严格尺寸公差和无缺陷的高质量铸件的需求正在增长（表 11.2）。

TABLE 11.2 General Characteristics of Casting Processes

Process	Typical materials cast	Weight (kg)		Typical surface finish	Porosity*	Shape complexity*	Dimensional accuracy*	Section thickness (mm)	
		Minimum	Maximum	(μm, R_a)				Minimum	Maximum
Sand	All	0.05	No limit	5 ~ 25	4	1 ~ 2	3	3	No limit
Shell	All	0.05	100 +	1 ~ 3	4	2 ~ 3	2	2	—
Expendable mold pattern	All	0.05	No limit	5 ~ 20	4	1	2	2	No limit
Plaster mold	Nonferrous (Al, Mg, An, Cu)	0.05	50 +	1 ~ 2	3	1 ~ 2	2	1	—
Investment	All (High melting pt.)	0.005	100 +	1 ~ 3	3	1	1	1	75
Permanent mold	All	0.5	300	2 ~ 3	2 ~ 3	3 ~ 4	1	2	50
Die	Nonferrous (Al, Mg, Zn, Cu)	< 0.05	50	1 ~ 2	1 ~ 2	3 ~ 4	1	0.5	12
Centrifugal	All	—	5000 +	2 ~ 10	1 ~ 2	3 ~ 4	3	2	100

* Relative rating: 1 best, 5 worst.

Note: These ratings are only general; significant cariations can occur, depending on the methods used.