“十二五”普通高等教育本科规划教材

材料成型及控制工程专业英语教程

范小红　徐勇　主编

化学工业出版社

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·北京·

本书精选了材料成型及控制工程专业不同领域的英文课文，主要内容分为三部分，第一部分为铸造方面的内容，包括材料凝固理论、各种铸造成形方法以及计算机在金属铸造中的应用等；第二部分为塑性成型方面的内容，包括锻造工艺、冲压工艺、塑性成型设备以及计算机辅助工艺设计等；第三部分为焊接方面的内容，主要包括焊接的基本原理、各种焊接工艺、焊缝评价及质量控制等。每节课文后都附有专业技术词汇以及思考题，以利于学生阅读和理解课文，记忆和掌握词汇。

本书既可作为高等院校材料成型与控制工程专业的专业英语教学用书，也可作为相关专业科技人员的参考书。

图书在版编目（CIP）数据

材料成型及控制工程专业英语教程/范小红，徐勇主编．—北京：化学工业出版社，2013.10
“十二五”普通高等教育本科规划教材
ISBN 978-7-122-18412-2

Ⅰ.①材… Ⅱ.①范…②徐… Ⅲ.①工程材料-成型-英语-教材 Ⅳ.①H31

中国版本图书馆 CIP 数据核字（2013）第 216114 号

责任编辑：杨 菁 彭喜英　　文字编辑：林 丹
责任校对：顾淑云　　装帧设计：杨 北

出版发行：化学工业出版社（北京市东城区青年湖南街 13 号 邮政编码 100011）
印　　刷：北京市振南印刷有限责任公司
装　　订：三河市宇新装订厂
787mm×1092mm 1/16 印张 14¾ 字数 382 千字 2014 年 1 月北京第 1 版第 1 次印刷

购书咨询：010-64518888（传真：010-64519686） 售后服务：010-64518899
网　　址：http://www.cip.com.cn
凡购买本书，如有缺损质量问题，本社销售中心负责调换。

定　　价：33.00 元

前言

随着经济全球化的发展，国内制造业的产品出口份额迅速增加，同时也涌现了大量的合资及外资企业。加上国有大中型企业产品结构的调整，这些企业作为用人单位，对毕业生的外语提出了更高的要求，精通外语专业已成为对大中型企业工程技术人员的基本要求。

为了满足高等院校材料成型及控制工程专业本、专科教学需要，我们编写了本书。其中精选了铸造、塑性成型、焊接等方面的专业英语课文，并在文后对重要词汇进行了注释，提出了思考题；课文的选用依据覆盖面广、代表性强和短而精的原则，重点突出了与上述三个实际生产应用较多的专业方向有关的经典英语课文。对于材料成型及控制工程领域的专业人员来说也可在生产实践中参考本书。

本书由山东建筑大学范小红、徐勇主编，李静、赵忠魁、任国成、林晓娟、项东参与了教材的编写工作。山东建筑大学的许斌教授认真审阅了本书，并提出了许多宝贵意见。

在本书编写过程中，参考了国内外众多专家和同行的研究成果和著作，在此表示感谢。除所列参考文献之外，还参考了网络媒体上的讲义等文献资料，因这些资料来源难以考证，无法指明其准确出处，编者在此一并向其作者表示衷心的感谢。

由于编者水平有限，书中难免出现纰漏之处，恳请广大读者批评指正。

编　者

2013.11

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Part Ⅰ
Casting

Unit 1

Casting Advantages and Applications

● Introduction

Metal Casting is unique among metal forming processes for a variety of reasons. Perhaps the most obvious is the array of molding and casting processes available that are capable of producing complex components in any metal, ranging in weight from less than an ounce to single parts weighing several hundred tons. Foundry processes are available and in use that are economically viable for producing a single prototype part, while others achieve their economies in creating millions of the same part. Virtually any metal that can be melted can and is being cast. This article will examine the advantages of the metal casting process, the major applications of cast components, and the technical and market trends that are shaping the foundry industry and the products it produces.

It is estimated that castings are used in 90% or more of all manufactured goods and in all capital goods machinery used in manufacturing. The diversity in the end use of metal castings is a direct result of the many functional advantages and economic benefits that castings offer compared to other metal forming methods. The beneficial characteristics of a cast component are directly attributable to the inherent versatility of the casting process.

● Functional Advantages

Beyond the rapidly emerging technologies that are keeping metal casting in the forefront in the metal forming industry, castings possess many inherent advantages that have long been accepted by the design engineer and metal parts user. In terms of component design, casting offers the greatest amount of flexibility of any metal forming process. The casting process is ideal because it permits the formation of streamlined, intricate, integral parts of strength and rigidity obtainable by no other method of fabrication. The shape and size of the part are primary considerations in design, and in this category, the possibilities of metal castings are unsurpassed. The flexibility of cast metal design gives the engineer wide scope in converting his ideas into an engineered part.

The following list of functional advantages of castings and the metal casting process illustrate why castings have been and continue to be the choice of design engineers and materials specifiers.

Rapid Transition to Finished Product. The casting process involves pouring molten metal into a cavity that is close to the final dimensions of the finished component; therefore, it is the most direct and simplest metal forming method available.

Suiting Shape and Size to Function. Metal castings weighing from less than an ounce to hundreds of tons, in almost any shape or degree of complexity, can be produced. If a pattern can be made for the part, it can be cast.

Placement of Metal for Maximum Effectiveness. With the casting process, the optimum amount of metal can be placed in the best location for maximum strength, wear resistance, or the enhancement of other properties of the finished part. This, together with the ability to core out unstressed sections, can result in appreciable weight savings.

Optimal Appearance. Because shape is not restricted to the assembly of preformed pieces, as in welding processes, or governed by the limitations of forging or stamping, the casting process encourages the development of attractive, more readily marketable designs. The smooth, graduated contours and streamlining that are essential to good design appearance usually coincide with the conditions for easiest molten metal flow during casting. They also prevent stress concentrations upon solidification and minimized residual stress in the final casting.

Complex Parts as an Integral Unit. The inherent design freedom of metal casting allows the designer to combine what would otherwise be several parts of a fabrication into a single, intricate casting. This is significant when exact alignment must be held, as in high-speed machinery, machine tool parts, or engine end plates and housings that carry shafts.

Improved Dependability. The use of good casting design principles, together with periodic determination of mechanical properties of test bars cast from the molten metal, ensures a high degree of reproducibility and dependability in metal castings that is not as practical with other production methods. The functional advantages that metal castings offer and that are required by the designer must be balanced with the economic benefits that the customer demands. The growth of metal casting and its current stability are largely the result of the ability of the foundry industry to maintain this balancing act. The design and production advantages described above bring with them a variety of cost savings that other metal working processes cannot offer. These savings stem from four areas:

- The capability to combine a number of individual parts into a single integral casting, reducing overall fabrication costs.
- The design freedom of casting minimizes machining costs and excess metal.
- Patterns used in casting lower in cost compared to other types of tooling.
- Castings require a comparatively short lead time for production.

For these and because it remains the most direct way to produce a required metal shape, metal casting will continue to be a vitally important metal forming technology. The diversity in end use in castings is also evidence of the flexibility and versatility of the metal casting process. Major casting end uses and market trends are discussed below.

● Casting Market Trends and End Uses

The use of metal castings is pervasive throughout the economies of all developed countries, both as components in finished manufactured goods and as finished durable goods. As indicated earlier, castings are used in 90% of all manufactured goods and in all capital goods machinery used in manufacturing. They are also extensively used in transportation, building construction, municipal water and sewer systems, oil and gas pipelines, and a wide variety of other applications.

Industry Structure. In the broadest sense, foundries are categorized into two general groups: ferrous foundries (those that produce the various alloys of cast iron and cast steel) and nonferrous foundries (those that produce aluminum-base, copper-base, zinc-base, magnesium, and other nonferrous castings).

Ferrous castings shipments are usually classified by market category. For example, iron castings are generally categorized as engineered (designed for specific, differentiated customers) and non-engineered (produced in large volumes of interchangeable units, usually consisting of ingot molds, pressure and soil pipe).

The diversity among the various foundries makes it difficult to determine the exact structure of the industry. For example, it is not unusual for a single operating foundry to produce a variety of metals and alloys, both ferrous and nonferrous, in the same plant. Some also use a variety of processes in their operations. Many aluminum foundries, for instance, use both sand and permanent mold processes, and some event produce die castings in the same facility.

Casting End Uses. Metal castings have a great variety of end uses and are therefore largely taken for granted by the consuming public. Castings are often the hidden components of the machines and other equipment used on a daily basis, such as automobiles, lawn mowers, refrigerators, stoves, typewriters, and computers. Only in rare cases does a consumer make a conscious decision to buy a cast product unless it is readily identifiable, as in the case of cast iron or aluminum cookware, cast iron bathtubs, or ornamental products such as cast bronze sculptures.

Designers of industrial equipment and machinery, on the other hand, have long recognized the performance qualities of castings and regularly specify their use. These functional and economic advantages were described earlier. The major markets for cast products are listed in Table 1-1.

Ranked in order of tonnage shipped. In some cases, the total of "Other major markets" is larger as a whole than the individual markets listed.

Table 1-1 Major markets for metal castings

Gray iron	Ingot molds; Motor vehicles; Farm equipment; Engines; Construction machinery; Valves; Soil pipe; Pumps and compressors; Pressure pipe; Other major markets include machine tools, mechanical power transmission equipment, hardware, home appliances, and mining machinery, oil and natural gas pumping and processing equipment
Malleable iron	Motor vehicles; Valves and fittings; Construction machinery; Railroad equipment; Engines; Mining equipment; Hardware; Other major markets include heating and refrigeration, motors and generators, fasteners, ordnance, chains, machine tools, general industrial machinery
Ductile iron	Pressure pipe; Motor vehicles; Farm machinery; Engines; Pumps and compressors; Valves and fittings; Metalworking machinery; Other major markets include textile machinery, wood working and paper machinery, mechanical power and transmission equipment, motors and generators, refrigeration and heating equipment, air conditioning
Steel	Railroad equipment; Construction equipment; Mining machinery; Valves and fittings; General and special industrial machinery Motor vehicles; Metalworking machinery; Other major markets include steel manufacturing, spring goods, industrial material handling equipment, ships and boats, aircraft and aerospace

Aluminum	Auto and light truck; Aircraft and aerospace; Other transportation; Engines; Household appliances; Office machinery; Power tools; Refrigeration; Other major markets include machine tools, construction equipment, mining equipment, farm machinery, electronic and communication equipment, power systems, motors and generators
Magnesium	Power tools; Sporting goods; Anodes; Automotive; Other major markets include office machinery, health care, aircraft and aerospace
Copper-base	Valves and fittings; Plumbing brass goods; Electrical equipment; Pumps and compressors; Power transmission equipment; General machinery; Transportation equipment; Other major markets include chemical processing, utilities, desalination, petroleum refining
Zinc	Automotive; Building hardware; Electrical components; Machinery; Household appliances; Other major markets include scientific instruments, radio and television equipment, audio components, toys, sporting goods

● Vocabulary

molding *n*. 模塑；铸造；装饰用的嵌线
casting *n*. 铸造；铸件 *v*. 铸造
foundry *n*. 铸造，铸造类；铸造厂
prototype *n*. 原型；标准，模范
streamline *vt*. 使合理化；使成流线型 *n*. 流线；流线型 *adj*. 流线型的
pouring *v*. 倾泻；倾诉（pour 的 ing 形式） *n*. 浇注
cavity *n*. 腔；洞，凹处
finished *adj*. 完结的，完成的；精巧的
pattern *n*. 模式；图案；样品 *vt*. 模仿；以图案装饰 *vi*. 形成图案
unstressed *adj*. 无应力的
preform *vt*. 预先形成 *n*. 粗加工的成品
forging *n*. 锻造；锻件 *v*. 锻造
stamping *v*. 冲压 *n*. 冲压，冲击制品
fabrication *n*. 制造，建造；装配；伪造物
weldment *n*. 焊件；焊成件；焊接装配
ferrous *adj*. 亚铁的；铁的，含铁的
nonferrous *adj*. 非铁的；不含铁的
aluminum *n*. 铝
copper *n*. 铜；铜币 *adj*. 铜的 *vt*. 镀铜于
zinc *vt*. 镀锌于……；涂锌于…… *n*. 锌
magnesium *n*. 镁
shipment *n*. 装货；装载的货物
ingot *n*. 锭；铸块
bronze *n*. 青铜；青铜制品 *adj*. 青铜色的；青铜制的 *vt*. 镀青铜于
residual stress 残余应力

● Questions

1. Please explain the advantages of the metal casting process.
2. Please talk about the applications of metal casting.

Unit 2

Nucleation Kinetics

Nucleation Processes play a key role in the solidification of castings by controlling to a large extent the initial structure type, size scale, and spatial distribution of the product phases. During many solidification processes, the size scale of critical nucleation events is too small and the rate of their occurrence too rapid for accurate observation by direct methods. Nonetheless, nucleation effects in the solidification microstructure exert a strong influence on the grain size and morphology as well as the compositional homogeneity. The final microstructure is also modified by the crystal growth, fluid flow, and structural coarsening processes that are important in the later stages of ingot freezing.

● Nucleation Phenomena

Nucleation during solidification is a thermally activated process involving a fluctuational growth in the sizes of clusters of solids. Changes in cluster size are considered to occur by a single atom addition or by removal exchange between the cluster and the surrounding undercooled liquid. At small cluster sizes, the energetics of cluster formation reveal that the interfacial energy is dominant, as can be observed by noting that the ratio of surface area to volume of a sphere is $r/3$. For the smallest sizes, clusters are called embryos; these are more likely to dissolve than grow to macroscopic crystals. In fact, the excess interfacial energy due to the curvature of small clusters is the main contribution to the activation barrier for solid nucleation. This accounts for the kinetic resistance of liquids to crystallization and is manifested in the frequent observation of undercooling effects during solidification.

● Homogeneous Nucleation

The principal features of nucleation phenomena and the kinetics of the rate process during solidification can be illustrated in the simplest terms by using the capillarity model to evaluate the kinetic factors. With this approach, it is useful to examine first the case of homogeneous nucleation in which solid formation occurs without the involvement of any extraneous impurity atoms or other surface sites in contact with the melt. As a further simplification, only the case of isotropic interfacial energy is treated, but it should be recognized that anisotropic behavior can yield faceted cluster shapes. The energetics of cluster formation for a spherical geometry can be expressed in terms of a surface and a volume contribution as:

$$\Delta G(r) = 4\pi r^2 \sigma + \frac{4}{3}\pi r^3 \Delta G_v \quad (1\text{-}1)$$

where $\Delta G(r)$ is the free energy change to form a cluster of size r and $\Delta G_v = \Delta H_f \Delta T / T_f V_m$. The relationship in Eq (1-1) is characterized in Fig. 1-1, in which the activation barrier for nucleation, ΔG_{cr}, is reached at a critical size r_{cr} (that is, $d\Delta G(r)/dr=0$), as given by:

$$r_{cr}=\frac{2\sigma}{\Delta G_v}=\frac{2\sigma T_f V_m}{\Delta H_f \Delta T} \quad (1\text{-}2)$$

$$\Delta G_{cr}=\frac{16\pi\sigma^3}{3\Delta G_v^2}=\frac{16\pi\sigma^3 T_f V_m^2}{3\Delta H_f^2 \Delta T^2} \quad (1\text{-}3)$$

At increasing values of undercooling, r_{cr} is reduced ($r_{cr}\propto\Delta T^{-1}$) and G_{cr} is reduced more rapidly ($\Delta G_{cr}\propto\Delta T^{-2}$). A cluster is often considered to reach the stage of a nucleus capable of continued growth with a decreasing free energy when the size r_{cr} is achieved, but in fact stable nucleus growth ensues when the cluster size exceeds r_{cr} by an amount corresponding to (ΔG_{cr}- kT) in Fig. 1-1. The relationship between cluster size and the number of atoms in a cluster, n_{cr}, is expressed by ($n_{cr} V_a$) $=\frac{4}{3}\pi r_{cr}^3/3$ ($n_{cr} V_a$), where V_a is the atomic volume.

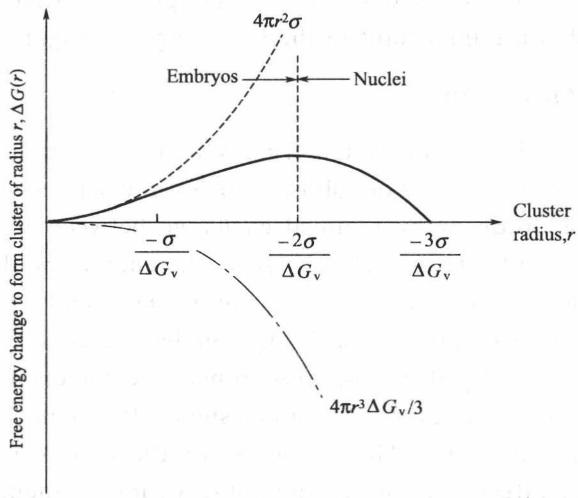

Fig. 1-1 Free energy change for cluster formation as a function of cluster size

● Heterogeneous Nucleation

Homogeneous nucleation is the most difficult kinetic path to crystal formation because of the relatively large activation barrier for nucleus development (ΔG_{cr}). To overcome this barrier, classical theory predicts that large undercooling values are required, but in practice an undercooling of only a few degrees or less is the common observation with most castings. This behavior is accounted for by the operation of heterogeneous nucleation in which foreign bodies such as impurity inclusions, oxide films, or crucible walls act to promote crystallization by lowering ΔG_{cr}. Because only a single nucleation event is required for the freezing of a liquid volume, the likelihood of finding a heterogeneous nucleation site in contact with a bulk liquid is great. Indeed, it has been estimated that even in a sample of high-purity liquid metal there is a nucleant particle concentration of the order of about 1012m^{-3}. Only by using special sample preparation methods to isolate the melt from internal and external nucleation sites by subdivision into a fine droplet dispersion has it been possible to achieve undercoolings in the range of 0.3 to $0.4T_f$.

The action of heterogeneous nucleation in promoting crystallization can be visualized in terms of the nucleus volume that is substituted by the existing nucleant, as illustrated schematically in Fig. 1-2. For a nucleus that wets a heterogeneous nucleation site with a contact angle θ, the degree of wetting can be assessed in terms of $\cos\theta = (\sigma_{nL} - \sigma_{nS})/\sigma_{LS}$, where the interfacial energies are defined in Fig. 1-2. As θ approaches 0, complete wetting develops; as θ approaches 180°, there is no wetting between the nucleus and the nucleant (which is inert), and the conditions approach homogeneous nucleation.

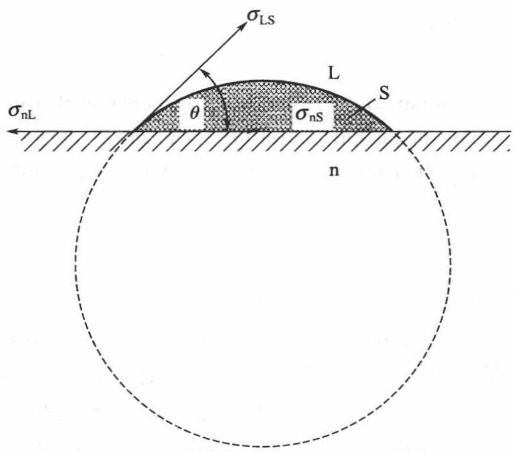

Fig. 1-2 The interfacial energy, σ, relationships among a planar nucleant substrate (n), a spherical sector solid (S), and the liquid (L)

The energetics of heterogeneous nucleation can be described by a modification of Eq (1-1) to account for the different interfaces and the modified cluster volume involved in nucleus formation. In terms of the cluster formation shown in Fig. 1-2, the free energy change during heterogeneous nucleation is expressed by:

$$\Delta G(r)_{het} = V_{SC}\Delta G_v + A_{SL}\sigma_{SL} + A_{nS}\sigma_{nS} - A_{nL}\sigma_{nL} \tag{1-4}$$

where V_{SC} is the spherical cap volume and A_{SL}, A_{nS}, and A_{nL}, are the solid-liquid, nucleant-solid, and nucleant-liquid interfacial areas, respectively. When the volume and relevant interfacial areas are expressed in terms of the geometry of Fig. 1-2, the evaluation of ΔG_{cr} for heterogeneous nucleation yields:

$$\Delta G_{cr}(het) = \frac{16\pi\sigma_{LS}^3}{3\Delta_v^2}\left[\frac{2 - 3\cos\theta + \cos^3\theta}{4}\right] = \Delta G_{cr}(hom)[f(\theta)] \tag{1-5}$$

The comparison between heterogeneous and homogeneous nucleation kinetics is illustrated in Fig. 1-3 by a schematic time-temperature transformation diagram. Although only a single transformation curve (that is, C-curve) is shown in Fig. 1-3 for heterogeneous nucleation, in reality there will be as many curves as the number of heterogeneous nucleation sites. Each curve for heterogeneous nucleation will be distinguished by a catalytic potency, that is, $f(\theta)$ and a site density. To attain homogeneous nucleation conditions, it is clear that all heterogeneous nucleation sites must be removed or bypassed kinetically.

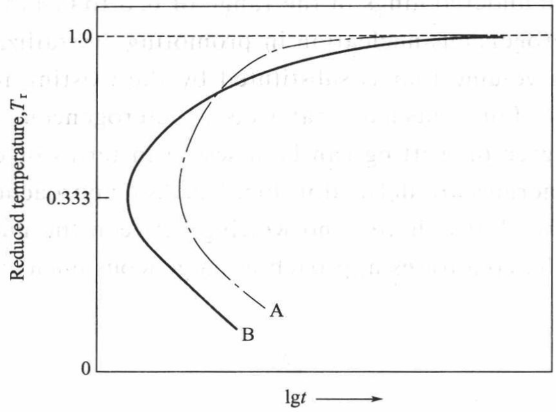

Fig. 1-3 Comparison between heterogeneous nucleation (A) and homogeneous nucleation (B) in terms of the relative transformation kinetics below the melting point

● Vocabulary

nucleation *n.* 成核现象；成核
solidification *n.* 凝固；团结；浓缩
undercooling *n.* 过冷；低冷却
vt. 使……过度冷却
supercooling *n.* 过冷 *v.* 使过冷
fluctuational *n.* 起伏，波动
crystallization *n.* 结晶化；具体化
anisotropic *adj.* 各向异性的；非均质的
homogeneous *adj.* 均匀的；奇次的；同种的
nucleus *n.* 核，核心；原子核
heterogeneous *adj.* 多相的；异种的；不均匀的；由不同成分形成的
oxide *n.* 氧化物
nucleant *adj.* 形成核的
transformation *n.* 转化；转换；改革；变形
catalytic *adj.* 接触反应的；起催化作用的
n. 催化剂；刺激因素

● Questions

1. Please tell the principal features of nucleation phenomena.
2. Please tell the difference between heterogeneous and homogeneous nucleation.

Unit 3

Basic Concepts in Crystal Growth and Solidification

Crystal Growth and Solidification in metal castings is largely a function of atomic mobility. Thermal and kinetic factors must be considered when determining whether crystal growth will be inhibited or accelerated. Whether spherical or needle-like in configuration, the metal particles behave differently depending on their location within the composition: in the liquid, at the liquid/solid interface, or in the solid.

● Liquid and Solid State

Atomic Mobility. The solidification of metals results in an enormous and abrupt decrease in atomic mobility. The dynamic viscosity η of pure liquid metals near their melting temperature T_f is comparable to that of water at room temperature, that is, of the order of 10^{-3} Pa · s (10^{-2} P), as shown in both Table 1-2. On the other hand, the following observations can be made:

- In the solid state, metals and alloys have a high tensile strength.
- Pure metals resist stresses of the order of 10^4 Pa (1.5psi) near the melting point.
- The decrease in ductility of commercial alloys several hundred degrees below the solidus temperature is due to the presence of liquid films in the segregated zones.

Table 1-2 Physical properties of pure metals relevant to solidification

Property	Iron (δ)	Copper	Aluminum
Dynamic viscosity η of liquid at $T_f/10^{-3}$Pa · s	5.03	3.05	1.235
Melting point, T_f/K	1809	1356	933
Enthalpy of fusion per mole/(J/mol)	13.807	13.263	10.711
Enthalpy of fusion per volume/(10^9J/m^3)	1.93	1.62	0.95
Heat capacity C_P of liquid at T_f/[10^6J/(K · m^3)]	5.74	3.96	2.58
Heat capacity C_P of solid at T_f/[10^6J/(K · m^3)]	5.73	3.63	3.0
Thermal conductivity of liquid K_L at T_f/[W/(m · K)]	35	166	95
Thermal conductivity of solid K_S at T_f/[W/(m · K)]	33	244	210
Thermal diffusivity of liquid α_L at T_f/(10^{-6}m^2/s)	6.1	42	37

Heat release. during solidification is large—approximately 270MJ/tonne for steel. The higher the melting point of the metal, the larger the latent heat of fusion (Table 1-2). Therefore, solidification processing is initially a matter of extracting large quantities of heat quickly.

Solidification Shrinkage. Most metals shrink when they solidify. Solidification shrink-