Chapter 3

Casting Dies

3.1 Casting

The first castings were made during the period 4000 ~ 3000 B. 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. Many parts and components are made by casting, including cameras, carburetors, engine blocks, crankshafts, automotive components, agricultural and railroad equipment, pipes and plumbing fixtures, power tools, gun barrels, frying pans, and very large components for hydraulic turbines.

Casting can be done in several ways. The two major ones are sand casting, in which the molds used are disposable after each cycle, and die casting, or permanent molding, in which the same metallic die is used thousands or even millions of times. Both types of molds have three common features. They both have a "plumbing" system to channel molten alloy into the mold cavity. These channels are called sprues, runners, and gates (Fig. 3-1). Molds may be modified by cores which form holes and undercuts or inserts that become an integral part of the casting. Inserts strengthen and reduce friction, and they may be more machinable than the surrounding metal. For example, a steel shaft when properly inserted into a die cavity results in an assembled aluminum step gear after the shot.

After pouring or injection, the resulting castings require subsequent operations such as trimming, inspection, grinding, and repairs to a greater or lesser extent prior to shipping. Premium-quality castings from alloys of aluminum or steel require x-ray soundness that will be acceptable by the customer.

Certain special casting processes are precision-investment casting, low-pressure casting, and centrifugal casting.

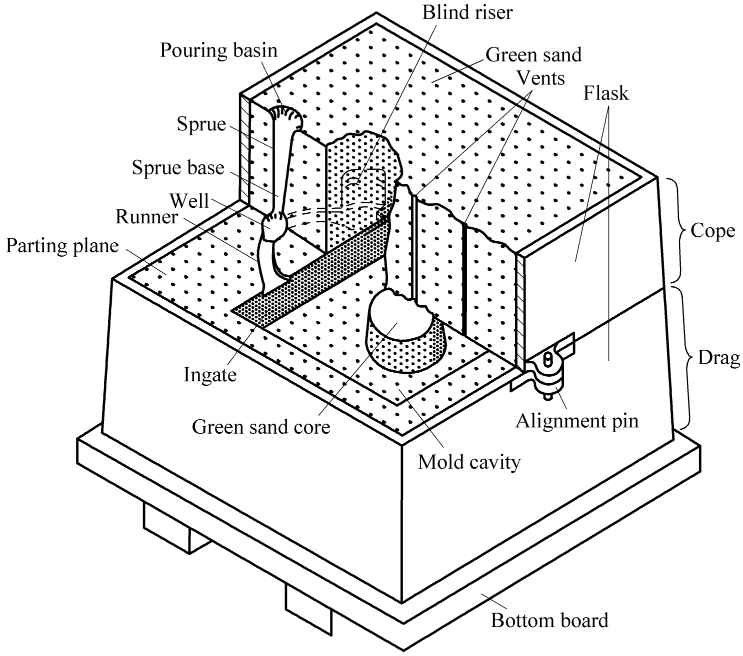

Fig. 3-1 A typical mold partially sectioned to show detail

New Words and Expressions

metal mold 金属模
copper 铜
camera 照相机
carburetor 汽化器
engine block 发动机组(本体)
crankshaft 曲轴,曲柄轴
automotive component 自动推进部件
plumbing fixture 管道夹具
power tool 电动工具
gun barrel 炮筒,枪筒
frying pan 煎锅,长柄平锅
sand casting 砂型铸造
channel 流道
runners 分流道
gate 浇口
machinable 可加工的
steel shaft 钢杆
aluminum 铝
pouring 浇注
shipping 发货,装运
premium-quality 第一流的质量
X-ray X 射线
precision-investment casting 精密熔模铸造
low-pressure casting 低压铸造
centrifugal casting 离心铸造法

3.2 Sand Casting

The traditional method of casting metals is in sand molds and has been used for millennia. Simply stated, sand casting consists of (a) placing a pattern having the shape of the desired casting in sand to make an imprint, (b) incorporating a gating system, (c) filling the resulting cavity with molten metal, (d) allowing the metal to cool until it solidifies, (e) breaking away the sand mold, and (f) removing the casting (Fig. 3-2). The production steps for a typical sand-casting operation are shown in Fig. 3-3.

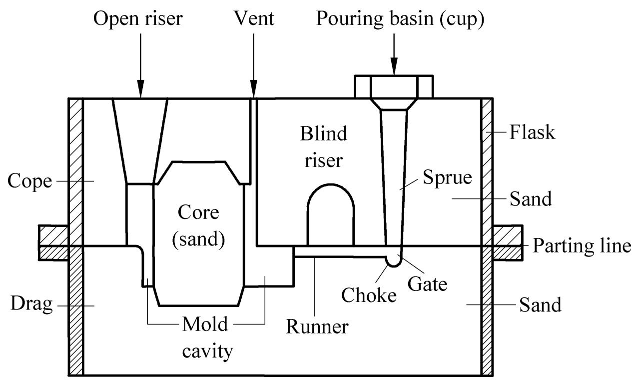

Fig. 3-2 Schematic illustration of a sand mold

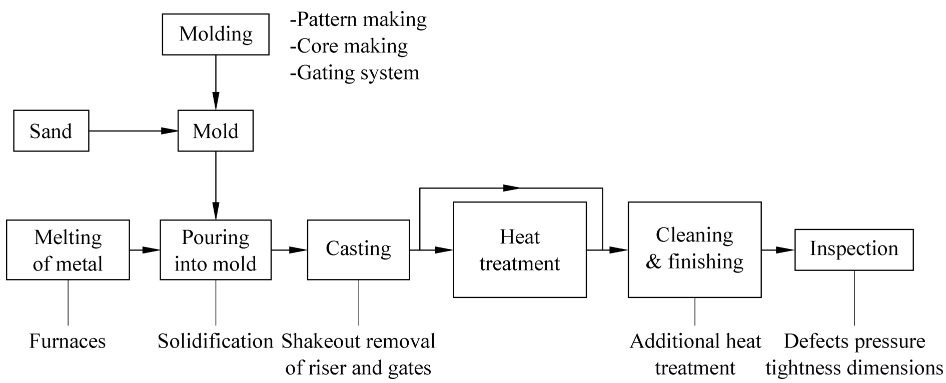

Fig. 3-3 Outline of production steps in a typical sand-casting operation

Although the origins of sand casting date to ancient times, it is still the most prevalent form of casting. In the United States alone, about 15 million tons of metal are cast by this method each year.

3.2.1 Sands

Most sand casting operations use silica sand (SiO_2), which is the product of the disintegration of rocks over extremely long periods of time. Sand is inexpensive and is suitable as mold material because of its resistance to high temperatures. There are two general types of sand: naturally bonded (bank sand) and synthetic (lake sand). Because its composition can be controlled more accurately, synthetic sand is preferred by most foundries.

Several factors are important in the selection of sand for molds. Sand having fine, round grains can be closely packed and forms a smooth mold surface. Although fine-grained sand enhances mold strength, the fine grains also lower mold permeability. Good permeability of molds and cores allows gases and steam evolved during casting to escape easily.

3.2.2 Types of Sand Molds

Sand molds are characterized by the types of sand that comprise them and by the methods used to produce them. There are three basic types of sand molds: greensand, cold-box, and no-bake molds.

The most common mold material is green molding sand, which is a mixture of sand, clay, and water. The term "green" refers to the fact that the sand in the mold is moist or damp while the metal is being poured into it. Greensand molding is the least expensive method of making molds.

In the skin-dried method, the mold surfaces are dried, either by storing the mold in air or by drying it with torches. These molds are generally used for large castings because of their higher strength.

Sand molds are also oven dried (baked) prior to pouring the molten metal; they are stronger than greensand molds and impart better dimensional accuracy and surface finish to the casting. However, this method has drawbacks: distortion of the mold is greater; the castings are more susceptible to hot tearing because of the lower collapsibility of the mold; and the production rate is slower because of the drying time required.

In the cold-box mold process, various organic and inorganic binders are blended into the sand to bond the grains chemically for greater strength. These molds are dimensionally more accurate than greensand molds but are more expensive.

In the no-bake mold process, a synthetic liquid resin is mixed with the sand; the mixture hardens at room temperature. Because bonding of the mold in this and in the cold-box process takes place without heat, they are called cold-setting processes.

The following are the major components of sand molds (Fig. 3-2):

(1) The mold itself, which is supported by a flask. Two-piece molds consist of a cope on top and a drag on the bottom. The seam between them is the parting line. When more than two pieces are used, the additional parts are called cheeks.

(2) A pouring basin or pouring cup, into which the molten metal is poured.

(3) A sprue, through which the molten metal flows downward.

(4) The runner system, which has channels that carry the molten metal from the sprue to the mold cavity. Gates are the inlets into the mold cavity.

(5) Risers, which supply additional metal to the casting as it shrinks during solidification. Fig. 3-2 shows two different types of risers: a blind riser and an open riser.

(6) Cores, which are inserts made from sand. They are placed in the mold to form hollow regions or otherwise define the interior surface of the casting. Cores are also used on the outside of the casting to form features such as lettering on the surface of a casting or deep external pockets.

(7) Vents, which are placed in molds to carry off gases produced when the molten metal

comes into contact with the sand in the mold and core. They also exhaust air from the mold cavity as the molten metal flows into the mold.

3.2.3 Patterns

Patterns are used to mold the sand mixture into the shape of the casting. They may be made of wood, plastic, or metal. The selection of a pattern material depends on the size and shape of the casting, the dimensional accuracy, the quantity of castings required, and the molding process.

Because patterns are used repeatedly to make molds, the strength and durability of the material selected for patterns must reflect the number of castings that the mold will produce. They may be made of a combination of materials to reduce wear in critical regions. Patterns are usually coated with a parting agent to facilitate their removal from the molds.

Patterns can be designed with a variety of features to fit application and economic requirements. One-piece patterns, also called loose or solid patterns, are generally used for simpler shapes and low-quantity production. They are generally made of wood and are inexpensive. Split patterns are two-piece patterns made such that each part forms a portion of the cavity for the casting; in this way, castings with complicated shapes can be produced.

Match-plate patterns are a popular type of mounted pattern in which two-piece patterns are constructed by securing each half of one or more split patterns to the opposite sides of a single plate (Fig. 3-4). In such constructions, the gating system can be mounted on the drag side of the pattern. This type of pattern is used most often in conjunction with molding machines and large production runs to produce smaller castings.

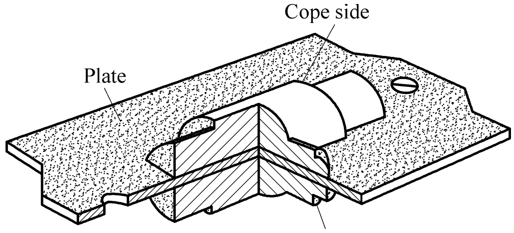

Fig. 3-4 A typical metal match-plate pattern used in sand casting

An important recent development is the application of rapid prototyping to mold and pattern making. In sand casting, for example, a pattern can be fabricated in a rapid prototyping machine and fastened to a backing plate at a fraction of the time and cost of machining a pattern. There are several rapid prototyping techniques with which these tools can be produced quickly.

Pattern design is a crucial aspect of the total casting operation. The design should provide for metal shrinkage, case of removal from the sand mold by means of a taper or draft (Fig. 3-5), and proper metal flow in the mold cavity.

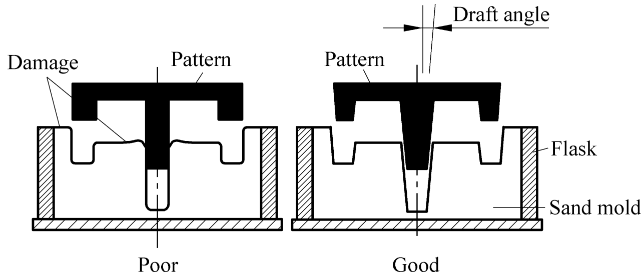

Fig. 3-5 Taper on patterns for case of removal from the sand mold

3.2.4 Cores

For castings with internal cavities or passages, such as those found in an automotive engine block or a valve body, cores are utilized. Cores are placed in the mold cavity before casting to form the interior surfaces of the casting and are removed from the finished part during shakeout and further processing. Like molds, cores must possess strength, permeability, ability to withstand heat, and collapsibility; therefore, cores are made of sand aggregates.

The core is anchored by core prints. These are recesses that are added to the pattern to support the core and to provide vents for the escape of gases (Fig. 3-6). A common problem with cores is that for some casting requirements, as in the case where a recess is required, they may lack sufficient structural support in the cavity. To keep the core from shifting, metal supports (chaplets) may be used to anchor the core in place (Fig. 3-6).

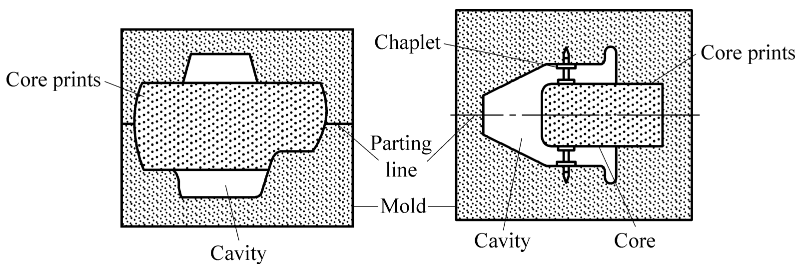

Fig. 3-6 Examples of sand cores showing core prints and chaplets to support cores

Cores are generally made in a manner similar to that used in making molds; the majority are made with shell, no-bake, or cold-box processes. Cores are formed in core boxes, which are used in much the same way that patterns are used to form sand molds. The sand can be packed into the boxes with sweeps, or blown into the box by compressed air from core blowers. The latter have the advantages of producing uniform cores and operating at very high production rates.

3.2.5 Sand-Molding Machines

The oldest known method of molding, which is still used for simple castings, is to compact the sand by hand hammering (tamping) or ramming it around the pattern. For most operations, however, the sand mixture is compacted around the pattern by molding machines (Fig. 3-7). These machines eliminate arduous labor, offer high-quality casting by improving the application and distribution of forces, manipulate the mold in a carefully controlled manner, and increase production rate.

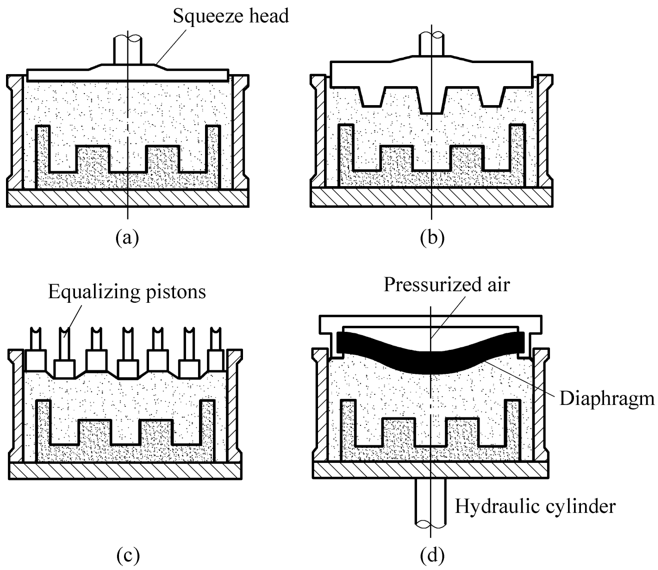

Fig. 3-7 Various designs of squeeze heads for mold making
(a) conventional flat head; (b) profile head; (c) equalizing squeeze pistons; (d) flexible diaphragm

Mechanization of the molding process can be further assisted by jolting the assembly. The flask, molding sand, and pattern are first placed on a pattern plate mounted on an anvil, and then jolted upward by air pressure at rapid intervals. The inertial forces compact the sand around the pattern. Jolting produces the highest compaction at the horizontal parting line, whereas in squeezing, compaction is highest at the squeezing head (Fig. 3-7). Thus, more uniform compaction can be obtained by combining squeezing and jolting.

In vertical flaskless molding, the halves of the pattern form a vertical chamber wall against which sand is blown and compacted (Fig. 3-8). Then, the mold halves are packed horizontally, with the parting line oriented vertically and moved along a pouring conveyor. This operation is simple and eliminates the need to handle flasks, allowing for very high production rates, particularly when other aspects of the operation (such as coring and pouring) are automated.

Sandslingers fill the flask uniformly with sand under high-pressure stream. They are used to fill large flasks and are typically operated by machine. An impeller in the machine throws sand from its blades or cups at such high speeds that the machine not only places the sand but also rams it appropriately.

In impact molding, the sand is compacted by controlled explosion or instantaneous release

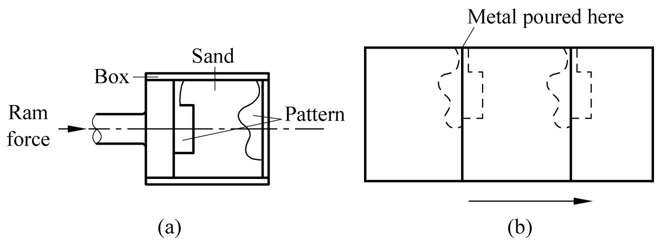

Fig. 3-8 Vertical flaskless molding

(a) sand is squeezed between two halves of the pattern; (b) assembled molds pass along an assembly line for pouring

of compressed gases. This method produces molds with uniform strength and good permeability.

In vacuum molding, also known as the "V" process, the pattern is covered tightly by a thin sheet of plastic. A flask is placed over the coated pattern and is filled with dry binderless sand. A second sheet of plastic is then placed on top of the sand, and a vacuum action hardens the sand so that the pattern can be withdrawn. Both halves of the mold are made this way and assembled.

During pouring, the mold remains under a vacuum but the casting cavity does not. When the metal has solidified, the vacuum is turned off and the sand falls away, releasing the casting. Vacuum molding produces castings with high-quality detail and dimensional accuracy. It is especially well suited for large, relatively flat castings.

3.2.6 The Sand Casting Operation

After the mold has been shaped and the cores have been placed in position, the two halves (cope and drag) are closed, clamped, and weighted down. They are weighted to prevent the separation of the mold sections under the pressure exerted when the molten metal is poured into the mold cavity.

The design of the gating system is important for proper delivery of the molten metal into the mold cavity. As described, turbulence must be minimized, air and gases must be allowed to escape by such means as vents, and proper temperature gradients must be established and maintained to minimize shrinkage and porosity. The design of risers is also important in order to supply the necessary molten metal during solidification of the casting. The pouring basin may also serve as a riser. A complete sequence of operations in sand casting is shown in Fig. 3-9. In Fig. 3-9(a), a mechanical drawing of the part is used to generate a design for the pattern. Considerations such as part shrinkage and draft must be built into the drawing. In (b) ~ (c), patterns have been mounted on plates equipped with pins for alignment. Note the presence of core prints designed to hold the core in place. In (d) ~ (e), core boxes produce core halves, which are pasted together. The cores will be used to produce the hollow area of the part shown in (a). In (f), the cope half of the mold is assembled by securing the cope pattern plate to the flask with aligning pins, and attaching inserts to form the sprue and risers. In (g), the flask is rammed with sand and the plate and inserts are removed. In (h), the drag half is produced in a similar manner, with the pattern inserted. A bottom board is placed below the drag and aligned with pins. In (i), the pattern, flask, and bottom board are inverted, and the pattern is withdrawn, leaving the appropriate imprint. In (j), the core is set in place within the drag cavity. In (k), the mold is closed by placing the cope on top of the drag and securing the assembly with pins. The flasks are then subjected to pressure to counteract buoyant forces in the liquid, which might lift the cope. In (l), after the metal solidifies, the casting is removed from the mold. In (m), the sprue and risers are cut off and recycled, and the casting is cleaned, inspected, and heat treated (when necessary).

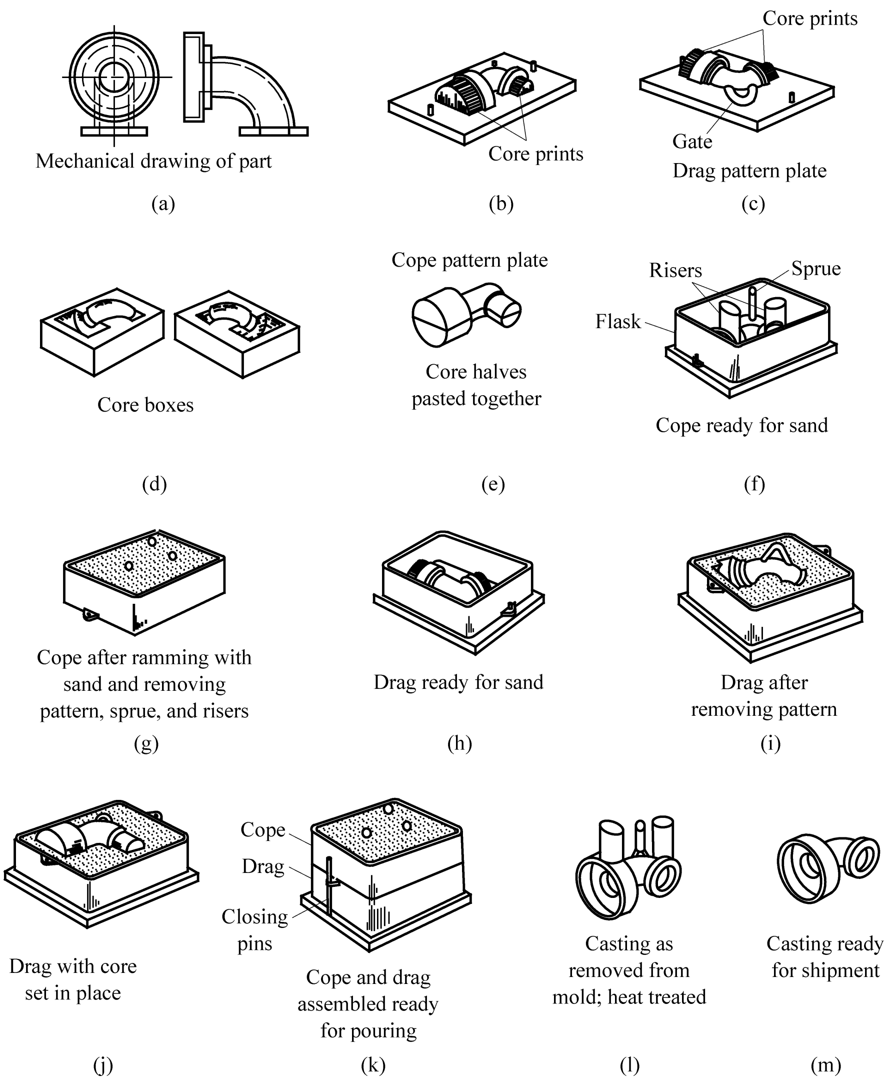

Fig. 3-9 Schematic illustration of the sequence of operations for sand casting

After solidification, the casting is shaken out of its mold, and the sand and oxide layers adhering to the casting are removed by vibration (using a shaker) or by sand blasting. Ferrous castings are also cleaned by blasting with steel shot (shot blasting) or grit. The risers and gates are cut off by oxyfuel-gas cutting, sawing, shearing, and abrasive wheels, or they are trimmed in dies. Gates and risers on steel castings are also removed with air carbon-arc or powder-injection torches. Castings may be cleaned by electrochemical means or by pickling with chemicals to remove surface oxides.

Almost all commercially-used metals can be sand cast. The surface finish obtained is largely a function of the materials used in making the mold. Dimensional accuracy is not as good as that of other casting processes. However, intricate shapes can be cast by this process, such as cast-iron engine blocks and very large propellers for ocean liners. Sand casting can be economical for relatively small production runs, and equipment costs are generally low.

The surface of castings is important in subsequent machining operations, because machinability can be adversely affected if the castings are not cleaned properly and sand particles remain on the surface. If regions of the casting have not formed properly or have formed incompletely, the defects may be repaired by filling them with weld metal. Sand-mold castings generally have rough, grainy surfaces, depending on the quality of the mold and the materials used.

The casting may subsequently be heat-treated to improve certain properties needed for its intended service use; these processes are particularly important for steel castings. Finishing operations may involve machining straightening, or forging with dies to obtain final dimensions.

Minor surface imperfections may also be filled with a metal-filled epoxy, especially for cast-iron castings because they are difficult to weld. Inspection is an important final step and is carried out to ensure that the casting meets all design and quality control requirements.

New Words and Expressions

pattern 模型
imprint 留下烙印
riser 冒口
cope 上型箱
silica sand 硅砂
bank sand 岸砂(黏土少于5%的天然砂,铸造用砂)
synthetic sand 合成砂
lake sand 湖砂
foundry 铸造,翻砂,铸造厂
permeability 渗透性
green-sand mold 湿(砂)型
cold-box mold 低温铸模
torch 割炬,焊炬,喷管,切割器
drawback 缺点,障碍
collapsibility 崩溃性,退让性
binder 黏结剂,曲面压碎圈,双动压力机外滑块
cold-setting process 冷塑(固)化过程
flask 型(砂)箱
drag 阻力,制动,牵制
cheek 耐火侧墙
pouring basin 浇口杯
pouring cup 浇口杯,外浇口
inlet 入口
blind riser 暗冒口