GASTROW

Injection Molds

2nd Edition

108 Proven Designs

HANSER

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2nd updated and revised edition with new mold designs

Edited by
E. Lindner and P. Unger

HANSER

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The examples of molds contained in this book represent to a large extent designs that have been proven in actual operation or those that have been prepared in accordance with current technical standards.
Nevertheless, neither the authors, editors or publishers can provide any guarantee that the designs are free from error and will function without difficulty if design details or the design itself are used.

Translated by Dr. Kurt A. Alex, Rumford RI, USA

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Gastrow
Injection Molds
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Preface to the second edition

The second English edition of Gastrow is now here. Since the appearance of the 1st (German) edition of this interpretative collection of tested and proven mold designs more than twenty-five years ago, this book has served two generations of designers and mold makers as a reference work and problem solver. This is also the intent of this new edition of Gastrow. It was not supposed to be a text book either then or now.
This new edition has been revised extensively. A large number of new molds representing the state of the art has been included. The computational methods given in earlier editions have been eliminated completely, since these are treated in a more up to date fashion and in greater detail in other literature (e. g. in Menges, Mohren "How to Make Injection Molds", 2nd edition, Carl Hanser Publishers). Whenever possible, the particular tool steels used have been listed with the respective examples. Accordingly, it appeared necessary to add a new chapter on material selection and surface treatment methods.
The 2nd edition is easier to use: an overview (p. 17) with references to the particular design employed for a given mold simplifies the use of the book. Following the previous tradition, the spectrum of molds presented extends from the simplest design to those exhibiting the highest degree of difficulty. Nevertheless, all molds have one thing in common: each contains some special know-how, and they demonstrate the high technical standards moldmaking has reached today.
The editors wish to thank all authors for their contributions to this new "Gastrow" and especially the translater Dr. Kurt Alex who prepared this English edition.

Fall 1992 The Editor

Preface to the first edition

Hans Gastrow has been publishing examples of mold construction for injection molding since the mid-fifties. These were collected and published in 1966 in the first German edition of this book, which was widely acclaimed because there had been, until then, no other collection of its kind. The injection molding industry stood at the beginning of its great upturn and ideas for constructing good and economically feasible molds were received with great interest. Shortly after the publication of the first edition, Gastrow died. The second edition, published in 1975, kept the objectives set by the first. It does not aim to be a textbook but illustrates selected problems of injection mold construction with interesting and commercially tested solutions. Some of the examples from the original *Gastrow* were retained; others, from younger specialists, were added. The present English translation of the third German edition remains true to this principle. Along with a large number of new examples, principles of construction are also treated. At the time of the second edition's publication, some of them did not possess their present topicality, as for example, hot-runner molds. The solutions to the problems illustrated include molds from the simplest technology to the most complex multi-stage molds.

Summer 1983 The Editor

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1 Principles of mold design

Critical analysis of a large number of injection molds for parts from all areas of application leads to the realization that there are certain classes and groups that differ from one another in some basic manner. Naturally, such a classification cannot contain all possible combinations of the individual classes and groups if it is to remain clear. It is conceivable that new knowledge and experience will require expansion and reorganization.

Nevertheless, such a classification fulfills its purpose if it conveys the previously collected experience with regard to mold design as clearly and thoroughly as possible. When working on a new problem, the mold designer can then see how such a mold is to be designed or was designed in similar cases. He will always, however, make an effort to evaluate the previous experience and create something even better instead of simply keeping to what was done previously. One basic requirement that must be met by every mold that is intended to run on an automatic injection molding machine is that the molded parts be ejected automatically without the need for secondary finishing operations (degating, machining to final dimensions, etc.).

From a practical standpoint, the classification of injection molds should be accomplished on the basis of the major features of the design and operation. These include:

- the type of gating/runner system and means of separation,
- the type of ejection used for the molded parts,
- the presence or absence of external or internal undercuts on the part to be molded,
- the manner in which the molded part is released.

Fig. 1.1 shows a procedure to methodically plan and design injection molds.

The finite element method (FEM) along with computational methods such as Cadform, Cadmould, Moldflow, etc. are being used increasingly to design and dimension parts and the associated injection molds. With these methods, development time and costs can be saved, while the serviceability of the molded parts is optimized.

The final mold design can be prepared only after the part design has been specified and all requirements affecting the design of the mold have been clarified.

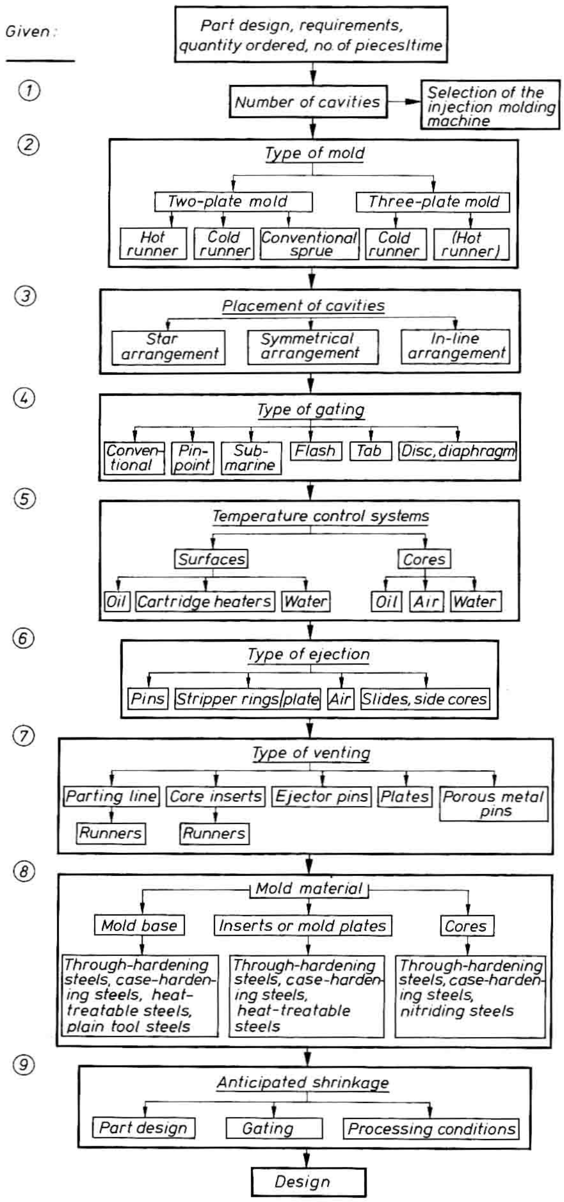

Fig. 1.1 Flow chart for methodical designing of injection molds

1.1 Types of injection molds

The German standard DIN E 16 750 "Injection and Compression Molds for Molding Compounds" classifies molds on the basis of the following criteria:

- standard molds (two-plate molds),
- split-cavity molds (split-follower molds),
- stripper plate molds,
- three-plate molds,
- stack molds,
- hot-runner molds.

There are also cold-runner molds for runnerless processing of thermosetting resins in analogy to the hot runner molds used for processing thermoplastic compounds.

If it is not possible to locate runners in the mold parting line or each of the parts in a multiple-cavity mold is to be center-gated, a second parting line (three-plate mold) is required to remove the solidified runner or

melt must be conveyed by means of a hot runner system. In stack molds, two molds are connected one behind the other for all practical purposes without the need for doubling the clamp force. A prerequisite for such molds is a large number of relatively simple as well as shallow parts. Low production costs are the particular advantage of operating such a mold. Today, stack molds are equipped exclusively with hot runner systems that must satisfy quite stringent requirements with regard to thermal homogeneity in particular.
Ejector pins are used most often to eject the molded parts. They also often serve to vent the cavity. With electrical discharge machining (EDM) having become so common, proper venting has become increasingly important. Whereas cavities were previously built up from several components with the possibility of incorporating effective venting at the respective mating surfaces, it is possible today by means of EDM to produce cavities in a solid block in many cases. Special care must thus be taken to assure that the melt displaces the air completely. Measures must also be taken to assure that entrapped air is avoided at particularly critical locations. A poorly vented cavity can lead to the formation of deposits in the mold, burning (the so-called diesel effect) and even corrosion problems. The size of a vent is determined primarily by the melt viscosity. Vents are generally between 0.01 mm and 0.02 mm in size. With extremely easy-flowing resins, vents on the order of $\geqq$ 0.001 mm in size may already be adequate. It should be noted, however, that effective cooling is generally not possible wherever a vent is placed.
Moving mold components must be guided and located. The guidance provided by the tiebars for the moving platen of an injection molding machine should be considered as rough alignment at best. "Internal alignment" within the injection mold is necessary in any case.
Tool steels are the preferred material for injection molds. Selection of the material should be made quite carefully on the basis of the resins to be processed. Requirements that must be met by the tool steels include:

- high wear resistance,
- high corrosion resistance,
- high dimensional stability, etc. (see also Section 1.10).

1.2 Types of runners and gates

1.2.1 Solidifying systems

According to DIN 24 450, a distinction is made between the:
- runner as part of the injection molded shot that does not belong to the molded part,
- runner system as the channel through which plasticated melt is conveyed from its point of entry into the mold up the gate,
- gate as the cross section of the runner system at the location where it feeds into the mold cavity.

The flow path of the melt into the cavity should be as short as possible in order to minimize pressure and heat losses. The type and location of runner/gate are of importance for:

- economical production,
- properties of the molded part,
- tolerances,
- weld lines,
- magnitude of molded-in stresses, etc.

The following provides an overview of the most commonly encountered types of solidifying runner systems and gates.

- Sprue (Fig. 1.2)
  Is generally used for relatively thick walled parts or for gentle processing of highly viscous melts. The sprue must be removed from the molded part after ejection takes place.

- Pinpoint gate (Fig. 1.3)
  In contrast to the sprue, the pinpoint gate is generally separated from the molded part automatically. If the gate vestige causes problems, the gate "d" can be located in a lens-shaped depression in the surface of the molded part. Commercially available pneumatic nozzles are also used for automatic ejection of a runner with pinpoint gate.

- Diaphragm gate (Fig. 1.4)
  The diaphragm is useful for producing, for instance, bushings with the highest possible degree of concentricity while avoiding weld lines. The necessity of having to remove the gate by means of subsequent machining is a disadvantage, as is the support of the core on only one side.

- Disk gate (Fig. 1.5)
  This is used preferably for internal gating of cylindrical parts in order to eliminate disturbing weld lines. With fibrous reinforcements such as glass fibers, for instance, the disk gate can reduce the tendency for distortion. The disk gate must also be removed subsequent to part ejection.

- Film gate (Fig. 1.6)
  To obtain flat molded parts with few molded-in stresses and little tendency to warp, a film gate over the entire width of the molded part is useful in providing a uniform flow front. A certain tendency of the melt to advance faster in the vicinity of the sprue can be offset by correcting the cross section of the gate. In single-cavity molds, however, the eccentric location of the gate can lead to opening of the mold on one side, with subsequent formation of flash. The film gate is usually trimmed off the part after ejection, but this generally does not impair automatic operation.

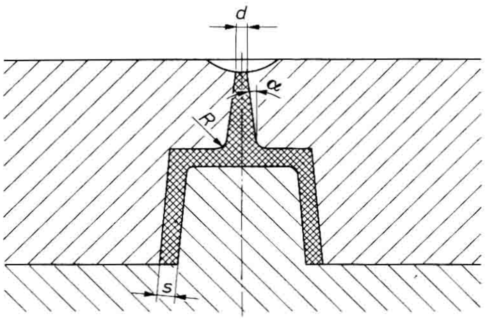

Fig. 1.2 Conventional sprue
a = draft, s = wall thickness, d = sprue (diameter), d ≧ s, d ≧ 0.5

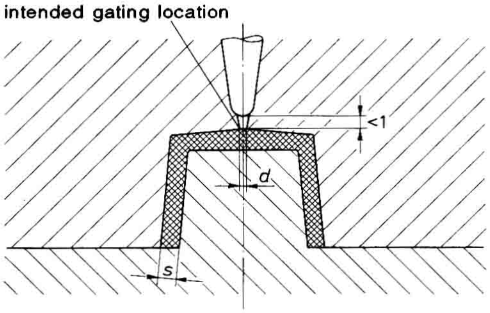

Fig. 1.3 Pinpoint gate, d ≦ 2/3 s

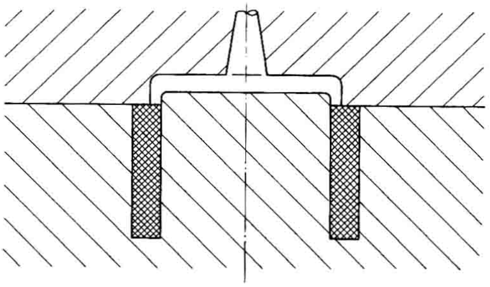

Fig. 1.4 Diaphragm gate

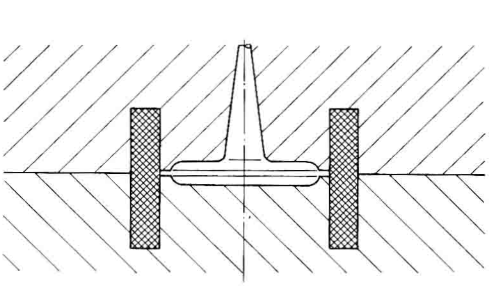

Fig. 1.5 Disk gate

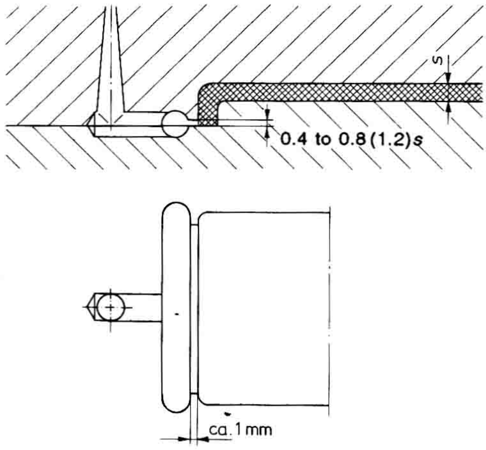

Fig. 1.6 Flash (film) gate preferred for large-area parts

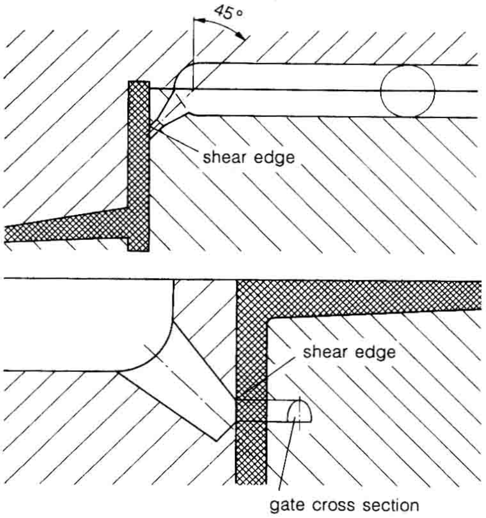

Fig. 1.7 Submarine (tunnel) gate

- Submarine gate (Fig. 1.7)
  Depending on the arrangement, this gate is trimmed off the molded part during opening of the mold or at the moment of ejection by means of a specified cutting edge. The submarine gate is especially useful when gating parts from the side. The lower part of Fig. 1.7 shows a submarine gating formed as a truncated cone. This design permits longer holding pressure times because of its greater cross section than the conical pointed gating in the upper part and prevents jetting during injection. With abrasive molded compounds, increased wear of the cutting edge in particular is to be expected. This may lead to problems with automatic degating.

Runner systems should be designed to provide the shortest possible flow paths and avoid unnecessary changes in direction while achieving simultaneous and uniform filling of cavities regardless of position in multi-cavity molds (assuming that all cavities are the same) and assuring that the duration of holding pressure is identical for each cavity.
Star- as well as ring-shaped runner systems (see Fig. 1.8) offer the advantage of identical and shortest possible flow paths. They are a disadvantage, however, when slides must be employed. In this case, in-line

runner systems (see Fig. 1.9 A) are useful, but have the disadvantage of unequal flow path lengths. This deficiency can, however, be offset to a very high degree by artificially balancing the runner system with the aid of a Moldflow analysis, for instance. This is achieved by varying the diameter of the runner channels, but not the cross section of the respective gates. A naturally balanced in-line runner system is shown in Fig. 1.9 B. This arrangement, however, generally leads to a relatively unfavorable ratio of molded part volume to runner system volume.

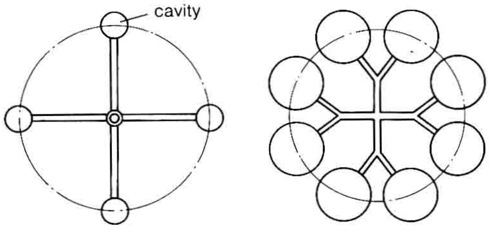

Fig. 1.8 Star-shaped runner

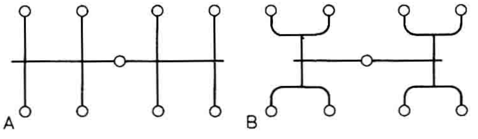

Fig. 1.9 In-line runners
A: unequal flow path lengths, B: equal flow path lengths

1.2.2 Hot-runner systems

Hot-runner systems are employed for so-called "runnerless" injection molding of parts in thermoplastic resins. It is also advantageous to use partial hot-runner systems, i. e. those with secondary runners. With proper design, lower pressure losses can be achieved in hot-runner systems than in comparable molds with solidifying runner systems. Thus, it is possible to produce extremely large parts such as automobile bumpers with suitable hot-runner systems.
Economical production of parts in stack molds has become possible only through the use of hot-runner technology.
By completely eliminating the solidifying secondary runners, the injection capacity of an injection molding machine can be better utilized. This may also result in a reduction in the filling time, which can be a reduction in cycle time. In principle, however, hot-runner systems do not reduce the cycle time.
The design principles employed for various hot-runner systems can differ considerably. This applies to both the hot-runner manifold and the hot-runner nozzles, the type and design of which can have a considerable influence on the properties of a molded part (Table 1).
The various hot-runner systems are not necessarily equally well suited for processing of all thermoplastics, even though this may be claimed occasionally. Thermally gentle processing of the melt to the greatest degree possible should be considered a particular criterion. From a heat transfer standpoint, this requires very involved design principles. Accordingly, hot-runner systems satisfying such requirements are more complex, more sensitive and possibly more prone to malfunction than conventional injection molds. As for the rest, the guidelines of precision machining must be observed to a very high degree when manufacturing such molds. When processing abrasive and/or corrosive molding compounds, the hot-runner system must be suitably protected. For instance, it may be necessary to take into consideration the incompatibility of the melt with respect to copper and copper alloys, which may lead to catalytically induced degradation. Suitably protected systems are available from suppliers. For the sake of better temperature control, hot-runner systems with closed-loop control should be given preference to those with open-loop control.
In medium-sized and, especially, large molds with correspondingly large hot-runner manifolds, "natural" or "artifical" balancing of the runners is successfully employed with the objective of obtaining uniform pressures or pressure losses. With "natural balancing", the flow lengths in the runner system are designed to be equally long. With "artifical balancing", the same result is achieved by varying the diameter of the runner channels as necessary. Natural balancing has the advantage of being independent of processing parameters such as temperature and injection rate, for example, but means that the manifold becomes more complicated, since the melt must generally now be distributed over several levels. An optimum hot-runner system must permit complete displacement of the melt in the shortest possible period of time (color changes), since stagnant melt can degrade thermally and thus result in reduced molded part properties.
Open hot-runner nozzles may tend to "drool". After the mold opens, melt can expand into the cavity

Table 1 Types of hot-runner systems

Component*	Type
Hot-runner manifold	externally heated internally heated
Manner of heating the hot-runner nozzles	externally heated, direct externally heated, indirect internally heated, direct internally heated, indirect internally and externally heated
Type of hot-runner nozzles	open nozzles, with or without torpedo; needle shutoff

* Designations as per DIN E 16750, issued July 1988

through the gate and form a cold slug that is not necessarily remelted during the next shot. In addition to surface defects, molded part properties can also be reduced in this manner as well. In an extreme case, a cold slug can even plug the gate.
With the aid of melt decompression (pulling back the screw before opening the mold), which is a standard feature on all modern machines, or with an "expansion chamber" in the sprue bushing of the hot-runner manifold, this problem can be overcome. Care must always be taken, however, that the decompression always be kept to a minimum in order to avoid sucking air into the sprue, runner system or region around the gate (avoidance of the diesel effect).
Although hot-runner technology has generally reached a high technical level, the user should be aware that more extensive maintenance by properly trained personnel is unavoidable.

1.2.3 Cold-runner systems

In a manner analogous to the so-called "runnerless" processing of thermoplastic resins, thermosets and elastomers can be processed without the loss of a runner system in cold-runner molds. This is all the more important, since crosslinked, or cured, runners generally cannot be regranulated. The objective of a cold-runner is to keep the thermoset or elastomer at a temperature level that precludes the possibility of crosslinking. As a result, the requirements placed on a cold-runner system are very stringent: the temperature gradient in the cold-runner system must be kept to an absolute minimum and optimum thermal separation of the mold and cold-runner must be provided in order to reliably prevent crosslinking of the resin. If, nevertheless, difficulties occur during operation, the mold must be so designed that the difficulty can be corrected without a great deal of work. Various types of cold-runner molds are described in greater detail in Sections 1.12 and 1.13.

1.3 Temperature control in injection molds

Depending on the type of resin to be processed, heat must be introduced to or removed from the injection mold. This task is handled by the mold temperature control system. Water or oil is usually employed to convey heat, while electrical heating of the mold is generally provided when processing thermosetting resins. A great deal of importance should be given to optimum temperature control. It has a direct influence on the functionality of the molded parts. The design and type of temperature control system influence:

- the warping of molded parts. This applies especially to semi-crystalline resins,
- the level of molded-in stresses in the part and thus its susceptibility to failure. With amorphous thermoplastics, the susceptibility to stress cracking can increase,
- the cooling time and thus also the cycle time.

The economics of a mold can be influenced significantly in this manner. Molds intended for the processing of amorphous thermoplastics are not necessarily equally well suited for the processing of semi-crystalline materials. The greater degree of processing shrinkage of semi-crystalline thermoplastics must be taken into account in most cases by providing a more uniform and higher-capacity temperature control system. This often means separate temperature control circuits in corner regions, for instance, keeping in mind that the temperature control circuit cannot be interrupted by the position of ejectors, slides or the like. The temperature difference between the inlet and outlet of the temperature control medium should not exceed 5 K. This often prevents series connection of temperature control circuits. Parallel connection or, even better, the use of several temperature control circuits each with its own temperature control unit is the preferred alternative in most cases. The magnitude of processing shrinkage is a direct function of the cavity wall temperature. Temperature differences in the mold and/or different cooling rates are thus responsible for warpage, etc. If water is employed as the temperature control medium, corrosion and calcium deposits in the temperature control circuits must be prevented, as otherwise the heat transfer and thus the effectiveness of the mold temperature control can be reduced.

1.4 Types of ejectors

As a consequence of the processing shrinkage, molded parts tend to be retained on mold cores (this does not necessarily hold true for parts molded of thermosetting resins). Various types of ejectors are used to release molded parts:

- ejector pins,
- ejector sleeves,
- stripper plates, stripper bars, stripper rings,
- slides and lifters,
- air ejectors,
- disc or valve ejectors, etc.

The type of ejector depends on the shape of the molded part. The pressure on the surface of the section of the molded part to be ejected should be as low as possible in order to avoid deformation. Profiled ejector pins should be prevented from turning.
Usually the mold cores and thus also the ejector mechanisms are located on the movable platen of the injec-

tion molding machine. In certain cases, it may be advantageous to attach the core to the stationary platen. In this case, special ejector mechanisms are required.
To release undercuts, slides are generally needed. Internal undercuts can be released by collapsible cores or internal slides. Threads may be released by:

- slides,
- removable inserts,
- collapsible cores,
- unscrewing cores, etc.

Undercuts which are intended to act, for instance, as snap fits can also be (forcibly) released directly, i. e. without the use of slides, lifters etc. It must be ensured, however, that the ejection temperature is considerably above room temperature and that the material stiffness is correspondingly low. The ejection forces must not lead to stretching of the molded part nor should ejectors be forced into the molded part. The permissible deformation during such forced ejection depends on the physical properties of the particular resin at the ejection temperature and on the design of the undercuts. A general statement with regard to the possibility of using (cost-reducing) forced ejection cannot be made. In principle, however, forced ejection should be taken into consideration when laying out a suitable mold.
Textured or grained surfaces generally act like undercuts. They thus require a certain minimum draft which, if not provided, can result in visible damage to the surface. As an approximate guideline to avoid such damage, the following value applies: per 1/100 mm of texture depth, approximately 1 degree of draft is needed.
Ejectors serve not only to release the molded parts, but are also needed to vent the cavity. Inadequate venting can lead, for instance, to

- incomplete filling of the cavity,
- inadequate welding where flow fronts meet,
- the so-called diesel effect, i. e. thermal degradation (burning) of the molded part, etc.

Problems with venting occur far from the gate especially.

1.5 Types of undercuts

Release of undercuts (see Section 1.4) generally requires additional design features in the mold such as opening of the mold along several planes, for instance. Additional release surfaces can be provided by slides and split cavities. Molds with slides release **external** undercuts with the aid of
- angle pins,
- cams,
- hydraulically or pneumatically actuated mechanisms.

Release of **internal** undercuts can be accomplished through the use of

- lifters
- split cores, which are actuated by means of a wedge,
- collapsible cores, which have smaller outside dimensions in the collapsed state than in the expanded state.

If release of threads is not possible by means of split cavities or slides, or if the witness line is undesirable, unscrewing molds are employed. These may utilize

- replaceable cores that are unscrewed outside the mold,
- threaded cores or threaded sleeves that release the threads in the molded part as the result of rotation during ejection. Actuation is accomplished either through the opening motion of the mold (lead screws, gear racks, etc.) or through the use of special unscrewing units.

Release of undercuts for short production runs can also be accomplished through the use of so-called "lost cores" (see also Section 1.6.1). When threads intended for fastening are involved, it is often more economical to mold throughholes instead of threads and then use commercially available self-tapping screws.

1.6 Special designs

1.6.1 Molds with fusible cores

Fusible core technology is employed to produce molded parts with cavities or undercuts that could not otherwise be released. Low melting point, reusable alloys on the basis of tin, lead, bismuth, cadmium, indium, antimony are employed. Depending on the composition, very different melting points result (lowest melting point approx. 50 °C). By introducing heat, e. g. inductive heating, the metallic core can be melted out of the molded part, leaving almost no residue.

1.6.2 Prototype molds of aluminum

The heat-treatable aluminum-zinc-magnesium-copper alloy (material no. 3.4365) has proven useful as a material for injection molds used to produce prototypes or small to medium production quantities. The advantages of this material, such as weight reduction, ease of machining, good thermal conductivity compared to tool steel, must be compared with the lower strength, reduced wear resistance, low stiffness as a result of the low modulus of elasticity and the relatively high coefficient of thermal expansion. In some cases, the properties of aluminum can be used to advantage in combination with steel.

1.6.3 Prototpye molds of plastics

To largely save on the cost-intensive machining needed to produce the part-forming surfaces in molds, curable casting resins can be employed. When strengthened by metal inserts or when reinforced with glass fibers, etc., such casting resins can also meet more stringent requirements within certain limits. The low wear resistance of casting resins must always be taken into consideration. Generally, such molds are used to produce prototypes or only small quantities of parts by means of injection molding.

1.7 Standard mold components

In order to produce injection molds economically, a large number of standard components that have been premachined to near-finished dimensions is available. These include (replaceable) mold components such as

- mold plates, clamping plates,
- inserts,
- guiding and locating elements,
- ejector pins and sleeves,
- latches,
- quick-clamp mechanisms,
- hot-runner manifolds,
- hot-runner nozzles,
- heating elements,
- positioning cylinders, etc.

Depending on requirements, some of these components are also available in different materials. The part to be molded as well as the injection mold itself can be designed with the aid of appropriate computer programs such as Cadform and Cadmould. Standard blanks of graphite or electrolytic copper are available to produce molds by means of electrical discharge machining (EDM).

1.8 Status of standardization

1.8.1 Standard components

The continued development of molds for the production of molded plastic parts is also reflected through standardization. In accordance with German standard DIN E 16 750, issued July 1988, the following mold components, among others, are standardized (Table 2).

Table 2 Standard components as per DIN E 16 750

Designation	DIN standard
Guide pins	9825, Part 1
Sprue bushings	16 752, Part 1
Sprue retainer bushings	16 757
Ejector sleeves with a cylindrical head	16 756
Ejector pins with a cylindrical head	1530, Part 1
Ejector pins with a cylindrical head and stepped-down shank	1530, Part 2
Ejector pins with a tapered head	1530, Part 3
Ejector pins with a cylindrical head and rectangular shank (blade ejector)	1530, Part 4

1.8.2 Injection mold for producing test specimens of thermoplastic resins

In order to directly compare the physical properties – as determined from test specimens – of thermoplastic resins from different material suppliers, the so-called Campus data bank (Kunststoffe/German Plastics 79 (1989) 8, p. 713) was developed in 1988. As a supplement, a corresponding standard for an injection mold to produce test specimens in a uniform manner is being prepared by the Plastics Technical Standards Committee 304.2. The mold consists of a frame with interchangeable inserts in which the cavities to produce the respective test specimens (e. g. 2-cavity tensile bar) are located. The mold is equipped with self-closing couplings for the temperature control system so that rapid and problem-free replacement of the inserts is possible. In order to process high-temperature resins characterized by relatively high melt and cavity wall temperatures, only tool steels with suitable properties are to be used (see also Section 1.9). The inserts can be preheated to provide the necessary cavity wall temperatures in a separate preheating station so that replacement of one mold insert with another involves the least possible amount of time.

1.9 Material selection

1.9.1 General

With the objective of achieving high functionality, different requirements are placed on the materials used to produce injection molds:

- *High wear resistance*
  In order to increase the stiffness of molded parts, for instance, reinforcements in the form of glass fibers, mineral fillers, etc. are used extensively. These, as well as some pigments, promote wear. Selection of suitable materials and/or surface treatment is thus of great importance.

- *High corrosion resistance*
  Aggressive components such as flame retardants or even the melt itself can chemically attack the part-forming surfaces. When combined with abrasive fillers and reinforcements, cumulative mold dam-

age may result. Corrosion-resistant steels or surface coatings, e. g. multi-layer chrome plating, are thus to be recommended.

- *Good dimensional stability*
  The processing of high-temperature plastics, for instance, requires cavity wall temperatures that can approach 250 °C. Tool steels with appropriate tempering properties (so-called hot work steels) are a prerequisite for this. Non-compliance with this requirement can lead to a change of the microstructure with temperature and thus to a dimensional change in the mold.
  The dimensional changes during heat treatment, e. g. case hardening, of the steel used must be small, but generally cannot be avoided (exception: maraging steels). Heat treatment of molds with large differences in cross section, for instance, is risky (distortion or cracking upon hardening, etc.). It is thus preferable to utilize prehardened steels that can be machined. Heat treatment after the machining can then, as a rule, be dispensed with. The strength and hardness of such steels however, is generally quite low. If, on the other hand, molds are produced by means of conventional electrical discharge machining, steels that have been tempered to the highest possible hardness can be employed.

- *Good thermal conductivity*
  Good mold temperature control is of great importance when processing semi-crystalline thermoplastics in particular. In order to affect the heat transport in a particular manner, variously alloyed steels may be employed. The effect of this measure on the thermal conductivity, however, is relatively modest. The noticeably higher thermal conductivity of copper, wrought copper alloys, etc. must be judged in light of the relatively low modulus of elasticity, relatively low hardness and low wear resistance. Depending on the type and quantity of alloying components, the mechanical properties can, however, be varied within certain limits. With each change, however, the thermal conductivity is also affected. The wear resistance can be improved noticeably with surface coatings, e. g. electroless nickel plating. It must not be forgotten, however, that in the event of surface or Hertzian pressure a hard surface layer may be penetrated as a result of inadequate support from the (soft) substrate. In addition to these requirements, the materials must furthermore exhibit good machineability, high purity and good polishability, etc.

1.9.2 Tool steels

The stiffness of a mold is independent of the steel selected, since the modulus of elasticity is practically identical for all common tool steels. Nevertheless, depending on the importance given to the various requirements, different materials may meet particular requirements better than others:

- case-hardened steels,
- prehardened steels,
- through-hardening steels,
- corrosion-resistant steels,
- special materials.

1.9.2.1 Case-hardening steels

These are low-carbon steels ($C \leqq 0.3\ \%$) that are given a hard, wear-resistant surface through case hardening (Table 3).
During the case hardening or carburizing (treatment temperature approx. 900 to 1000 °C), carbon diffuses into the near-surface regions of the material. The depth of case is a function of temperature and time. After case hardening for a lengthy period of time (several days), a depth of case of approx. 2 mm can be achieved. A hard, wear-resistant surface is achieved by quenching the carburized workpiece, while the core – assuming adequate workpiece thickness – in general remains tough.

1.9.2.2 Heat-treatable steels

Quenching and tempering is a heat treatment used to achieved increased toughness at a certain tensile strength. The treatment involves hardening with subsequent tempering at temperatures between 300 to 700 °C depending on the material and requirements. The available steels that have been treated in this manner (Table 4) are machined in the prehardened state. There is no subsequent hardening of the mold components. In this way, the risk of heat treating cracks and distortion upon hardening in particular is avoided.

1.9.2.3 Through-hardening steels (Table 5)

In order to achieve a uniform microstructure throughout even larger cross sections, through-hardening (alloyed) steels are used the hardness/strength and toughness of which can be matched to the particular requirements through heat treating (quenching and tempering). By selecting the temperature at which tempering takes place, these properties can be optimized. The through-hardening steels have proven very well suited for processing of abrasive molding compounds, e. g. those with glass fibers as a filler.

1.9.2.4 Corrosion-resistant steels (Table 6)

To protect against corrosive plastics or additives, there is always the possibility of electroplating the molds. One possible disadvantage, however, is that