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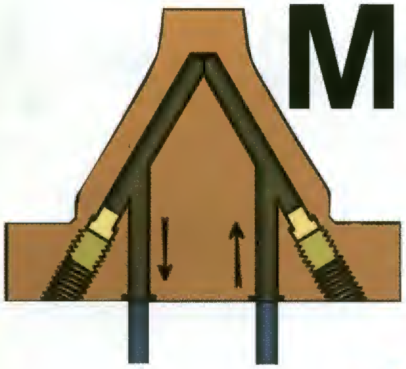

Mold Design Guidelines

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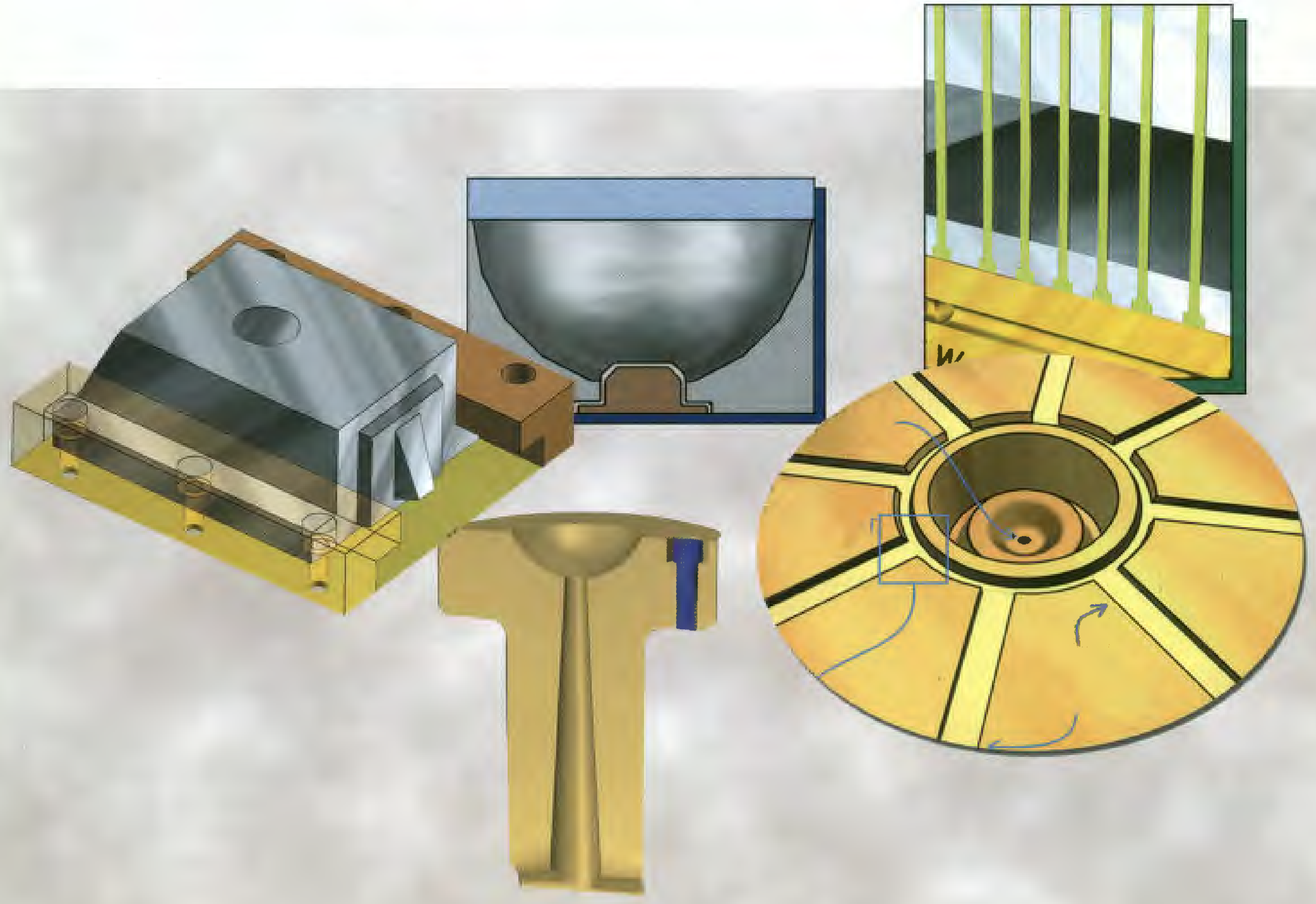

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Keep an eye out for coming issues of Modern Mold and Tooling, which will contain injection mold design guidelines developed to make you more productive. These informative and collectable fact-filled design guidelines are being developed for the injection molder, mold designer and mold builder. The information contained in the guidelines will maximize the mold's cycle time and improve part quality with the use of copper alloys in the mold.

The articles will begin in the May issue.

These information packed Injection Mold Design Guidelines are being developed and generated by The Copper-Alloy Molds Marketing Task Group. The group is a network of copper-alloy suppliers, distributors, and fabricators who have joined together to assist the moldmakers, molders and manufacturers to improve the processing of plastic materials. The task group, supported by the trade associations of the copper industry, is dedicated to research and disseminating the information you need to take advantage of the superior performance of molds containing copper-alloys. Also, the association is dedicated to developing an infrastructure of copper producers, fabricators, suppliers and mold makers who are in the plastics chain.

Research work, performed at Western Michigan University, is conducted to address technical issues and remove barriers to the use of copper alloys for plastic processing. The development of these Injection Mold Design Guidelines is a result of this research and in addition to empirical data derived from industry applications.

Companies and representatives, with contact information, serving on the Task Group include:

(For more informataion from these companies, write in the reader service number on the reader service card or fax-back page)

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Several molds, funded by the task group, were built and tested to conduct research under actual production conditions. One studied the cycle time advantage the copper alloys offered over traditional mold steels. Additionally, due to the superior thermal conductivity of the copper alloys, part quality improvements including less warpage, better dimensional stability and more uniform mold temperatures resulted. Other research and testing concentrated on eliminating mold sweating under humid operating conditions. This is accomplished by running higher mold operating temperatures with copper alloy mold cores. The test results prove that better part dimensional stability can be obtained at shorter mold cooling times without mold sweating when compared with mold steels.

Exhaustive wear study is under way

An exhaustive wear study is under way testing the effects of electroless nickel, hard chrome, titanium nitriting, thin dense chrome and thin dense chrome with diamond particulate in extending the mold life of the copper alloys.

As a service to the plastics industry, the Task Group is funding the publication of these guidelines in Modern Mold and Tooling. The greatest benefit to the people who deal with molds and molding will be to collect each issue to use as a reference in both the applications of the copper alloys and the mold design principles.

Subjects for the Injection Mold Design Guidelines will include:

1. Sprue Bushings and Runner Bars
2. Mold Cores, Core Pins and Chill Plates
3. Mold Cavities and "A" Side Inserts
4. Slides, Lifters and Raising Mold Members
5. Ejector Pins, Ejector Sleeves and Ejection
6. Mold Temperature Control Systems, Bubblers, Baffles, Diverters and Plugs
7. Wear plates, Slide Gibs, Interlock Plates, Leader pins and Guided Ejector Bushings
8. Plating and Coating of Copper Alloys
9. Application of Copper Alloys in Injection and Blow Molds

These guidelines will include properties of the various copper alloys most commonly utilized for their thermal and bearing properties, compared with traditional mold steels. Charts, graphs, formulas and descriptions will provide the user with pertinent data not available from other sources. ■

Injection Mold Design
Guidelines
Maximizing Performance Using Copper Alloys

**By Dr. Paul Engelmann
and Bob Dealey**
*for the Mold Marketing
Task Group of the Copper
Development Association*

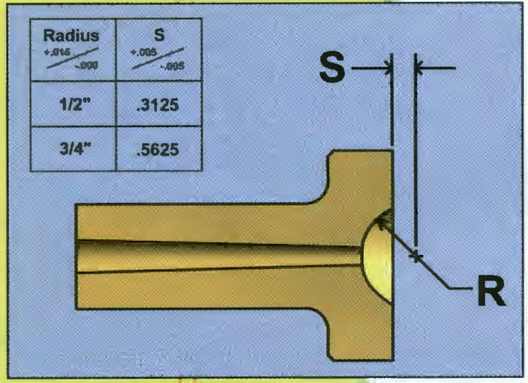


Illustration I, Sprue Radius

Copper Alloys for Conveying Plastic in Injection Molds

The high thermal conductivity of copper alloys makes them ideal materials for the injection mold sprue bushing and runner bars. Three alloys typically are utilized for the mold components, which will have contact with plastic. The copper alloys are:

- C17200, high hardness beryllium-copper alloy
- C17510, high conduct beryllium-copper alloy
- C18000, NiSiCr hardened high conductivity copper alloy

These Copper alloys have six to nine times greater heat transfer rates than conventional mold steels as indicated by the thermal conductivity.

Mold Material	Thermal Conductivity (Btu/Hr/Ft^2/°F)
C-17200	60
C-17510	135
C-18000	125
H-13	17
P-20	20
420 SS	14

The sprue or runner system must never control the cooling phase and/or overall molding cycle. Plastic in contact with copper alloys will set the sprue and runner faster, allowing more efficient ejection or removal by sprue pickers or robots.

Sprue Bushing Radius

In North America two injection mold nozzle and sprue bushing radii are used, 1/2 and 3/4 inch. To insure proper fit up, the nozzle radius is nominal -.015 inch, while the sprue radius is nominal +. 015 inch, required tolerances to use.

Swing points and tolerances used in establishing the radius on a sprue bushing are shown in illustration I.

Sprue Bushing Orifice

Machine nozzle orifices come in nominal 1/16" fractional inch sizes. To insure that the slug in the nozzle will pull through the sprue, the orifice must be .031 (1/32 inch) larger in diameter. This dimension is referred to as the "O" dimension. The relationship is shown in this chart.

Nozzle "O"	Sprue "O"
1/16"	3/32"
1/8"	5/32"
3/16"	7/32"
3/8"	9/32"
5/16"	11/32"
Nominal	+ 1/32"

Primary Runner Sizing Calculation

$$O_2 = O_1 + L\,(\text{TAN } 2.386°)$$

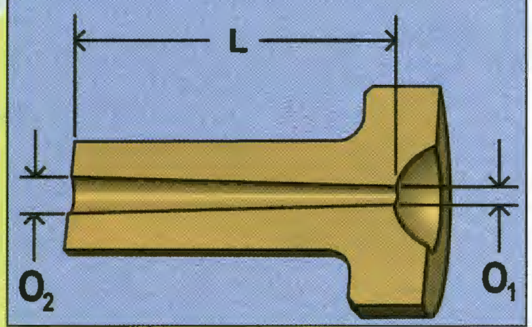


Illustration II, Sprue taper

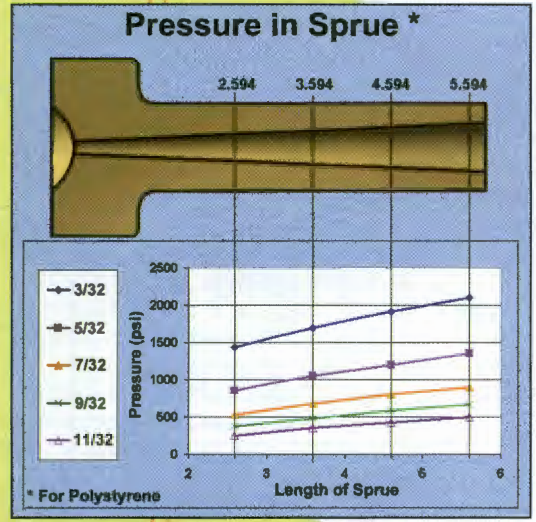


Illustration III, Pressure, Sprue Length

Illustration IV, Anti- rotation screw

$$E_R = \frac{A}{P}$$

E_R = Efficiency Ratio

A = Area of runner cross section

P = Periphery of runner cross section

Illustration V, Formula runner system

Sprue Bushing Taper

To aid in the removal of the sprue from the bushing, a taper of one-half inch per foot is normally used in injection molding. Calculate the sprue orifice at the parting line face, multiply the tangent of the taper angle times the length, plus the "o_2". Knowing this dimension, informed decisions can be made on primary runner sizing.

The sprue frequently controls the molding cycle when larger orifice conventional steel sprue bushings are used. The application of a copper alloy sprue bushing cools the sprue more quickly and efficiently, allowing the molding cycle to be controlled by the piece part.

Pressure loss is high in the sprue. This is the only place in the feed system where the channel progresses from a smaller area to larger. Frequently, smaller orifices are used on long sprue bushings in an effort to reduce the mass. This results in extremely high injection pressure losses, making the part hard to fill.

The chart in illustration III is a guide for determining the effect that the specific "O" dimension has on the pressure required to deliver plastic through the length of a sprue. Note that the difference between a 3/32 and 9/32-inch sprue is about 1,000 PSI over a short sprue and almost 1,500 pounds on a long sprue.

Using a copper alloy sprue bushing allows for an increased size orifice, thus reducing pressure loss while maintaining reasonable cooling times.

Sprue Retention and Anti-Rotation

Pressure acting on the parting line face of the sprue, due to projected area of the runner system or part detail, exerts pressure on the sprue bushing. Also, a sprue bushing that is not keyed will rotate creating misalignment with the runner machined into the face of the sprue bushing and the runner system. To prevent these problems, retain and key the sprue into position with the use of a cap screw as illustrated in figure IV.

Sprue Fit

Heat must be transferred from the sprue through the copper alloy sprue bushing to the mold plates. Interference fit is recommended for optimum cooling. The bore through the "A" plate should be nominal size to plus .0005 inches with a surface finish of at least 16 RMS. The shank of the sprue bushing should be the nominal size, plus .0005 to plus .001 inches.

Standard Sprue Bushing Availability

Copper alloy sprue bushings with patented stainless steel nozzle seats are commercially available. An insulator between the nozzle and sprue is beneficial in controlling the flow of heat from the nozzle to the sprue. Special sprue bushings may be constructed to suit using standard 1/2 inch per foot sprue bushing tapered drills and reams. Sprue bushings with tapers of up to 3/4 inch per foot have been used for difficult to remove plastics. Care must be taken to insure that the taper is draw polished and free from undercuts or rough surfaces that could hinder sprue removal.

Conventional Injection Mold Runner Systems

The shape of the runner, full round or trapezoidal, or other configuration, is dictated by mold design. The most efficient runner cross section is full round. The efficiency of the runner cross section can be calculated with a formula, Figure V, the larger the ratio the better.

Injection Mold Runner Bars

Runner systems for high cavitation molds normally have larger diameters due to runner balancing. The runner system extends the molding cycles as heat is slowly transferred from the thick plastic to steel mold plates. Inserting copper alloy runner bars in the mold "A" and "B" plates, cooling the runner faster, is beneficial, in reducing the overall molding cycle.

Runner Sizing

Runner sizing is dependent on many things, including: plastic material; part size, weight and wall thickness; molding machine capabilities and processing parameters and, the number and placement of the cavities.

Each mold is unique and the designer must consider all parameters and options available on an individual case by case basis. Several mold design software packages are available, including Mold Flow and C-Mold, which address sizing of the runner system.

One method of runner sizing and balancing used by mold designers' starts at the sprue and then works toward the gate. Other designers start with the part wall thickness and work back to the sprue outlet orifice. The normally recommended procedure is that, in the direction of plastic flow, the runner area always goes from larger to smaller. Never from a smaller area to a larger area.

When the primary runner diameter is known, the sum of the areas of the multiple connecting runners must be equal or smaller in area than the preceding runner. When working back from the part, some designers size the final runner channel size (that runner which feeds the gate) to equal the thickest wall section in the part. Each runner intersection then is a function of the area of that runner times the number of connecting runners, usually two. Therefore, the area of the upstream runner is always at least equal to or larger in area than the sum of the branches. Note that a runner with one-half the area is not the same as a runner of one-half the diameter.

Formulas for calculating the area of the runner:

Full Round Runner
A = 0.7854 d2

Trapezoidal Runner
A = (w1 + w2) h/2

A = area, d = diameter, l = length,
w = width, h = height

Runner Bar Mating

Best results are obtained by designing and building the runner bars to have zero to negative contact with each other when the mold is closed. This will prevent any deformation on the parting line surfaces that could result from high clamping pressures exceeding the compressive strength of the alloy. To accomplish this, the "A" and "B" runner bars should be flush to minus .001 inch on each side of the mold. This allows the mold base and/ or cavity and core inserts to receive machine clamp force, not the runner bars.

Care must be taken to understand the characteristics of the plastic being molded and clearance should be short of allowing the runner system to flash. Additionally, it is important to insure that the mating halves of the runner system are in perfect alignment, with no mismatch at the parting line, to maximize plastic flow efficiency.

Runner Bar Cooling

The runner system must never control the molding cycle. To insure proper temperature control of the runner bars, cooling channels should be placed directly into the both the "A" and "B" side inserts. The cross-drilled holes should be blocked with a plug containing an "O" ring and a straight thread plug. Due to the high thermal conductivity of the copper alloys and the tendency to thermal cycle rapidly, tapered thread systems must be avoided in the copper alloys to prevent cracking.

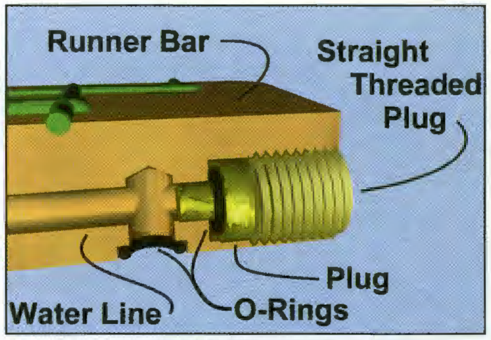


Illustration VI, Runner Bars

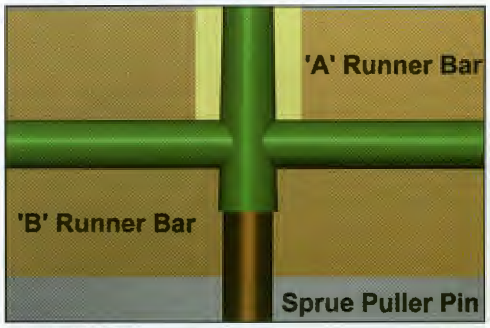


Illustration VII

With the increased cooling rate of the copper alloys and proper cooling arrangements, larger diameter runners can be used in a mold equipped with copper alloy runner bars. Almost without exception, runner diameters one or two sizes larger can be set up quicker with the copper alloys, over traditional mold steels.

Sprue Puller

A reverse taper sprue puller, 3° for stiffer materials and 5° for flexible materials, is recommended to insure sprue removal. To rapidly cool the undercut machine, the puller directly into the runner bars or a copper alloy insert. Illustration VII gives more details.

Acknowledgements

The injection mold design guidelines were written by Dr. Paul Engelmann, Associate Professor, Western Michigan University and Bob Dealey, Dealey's Mold Engineering, with the support of Dr. Dale Peters, for the Mold Marketing Task Group of the Copper Development Association. Kurt Hayden, graduate research assistant, WMU, generated the illustrations. Research conducted by WMU students in the plastics program.

Disclaimer

These guidelines are a result of research at WMU and industry experience gained with the use of copper alloys in injection molding. While the information contained is deemed reliable, due to the wide variety of plastics materials, mold designs and possible molding applications available, no warranties are expressed or implied in the application of these guidelines.

Contact Information

Information regarding copper alloys for molds and molding is available from the Copper Development Association, 1-800-232-3282.

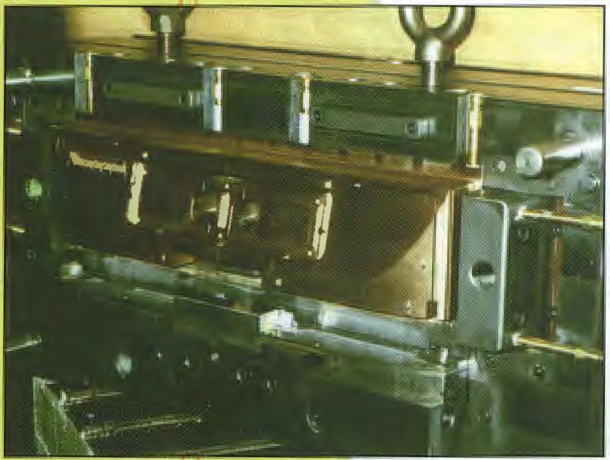
Injection Mold Design Guidelines

Maximizing Performance Using Copper Alloys

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

The Injection Mold Core

A mold core is any member that forms the interior of a plastic part, usually on the "B" side of the mold parting line. Mold cores can be machined from a solid piece of copper alloy or inserted to aid in construction or allow for easier replacement if a component would ever be damaged in molding.



Picture of Whirlpool mold: A core built from a copper alloy for a large dishwasher part

This picture shows a large copper alloy core, about 24 inches long and seven inches high, used to mold a PVC bezel for a Kitchen Aid dishwasher manufactured by Whirlpool Corporation, Findlay Ohio. The copper alloy was specified primarily to eliminate warpage on the part, which is both functional and esthetic in nature. The cycle time advantage of about 20% by using the high thermal conductive copper alloy was an added bonus to the improved part quality, which was the main objective.

Properly designed molds with copper alloys used in strategic locations, usually the core, have proven to reduce injection molding cooling cycles by 20 to 50 per cent. The mold core is responsible for removing from 65 to 75 per cent of the heat from the plastic molding due to the material shrinking around the standing features of the mold.

Copper alloys have adequate hardness levels to hold up against normal injection pressures found in conventional injection molding machines. The normal press (positive interference, or crush) is not used due to the higher ductility of copper alloys and to avoid any peening or hobbing at shut offs and at the parting line, Rather zero to negative press is recommended. Negative press or clearance of the mating components must obviously be less than that where plastic will flash. Hardness levels of the copper alloys and mold steels are listed in the following chart:

Hardness Levels

Copper Alloy	Hardness	Steel Alloy	Hardness
C17200	41 R_C	H-13	38/52 R_C
C17510	96 R_b	P-20	28-48 R_C
C18000	94 R_b	420 SS	27-50 R_C

The copper alloys normally selected for mold cores, core pins, inserts, slides and raising mold members are; C17200 a high hardness beryllium-copper alloy; C17510 a high conductivity beryllium-copper; And, C18000 a NiSiCr hardened high conductivity copper alloy. These alloys, with six to nine times greater heat trans-

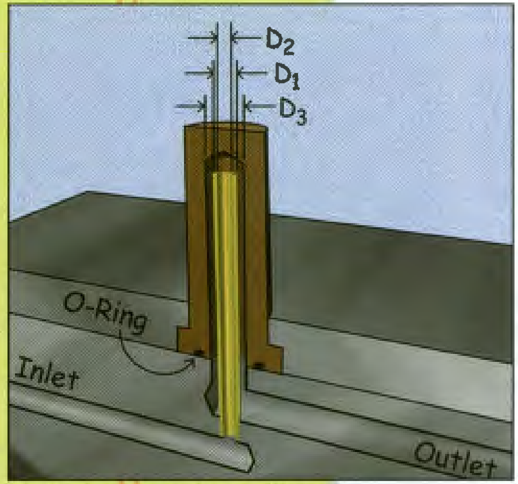


Illustration A: Heeled core with bubbler

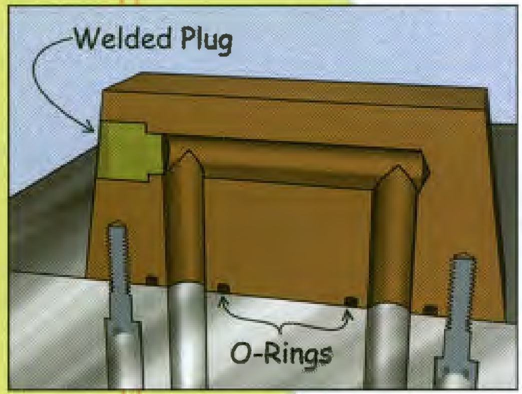


Illustration B: Inserted core with water channels

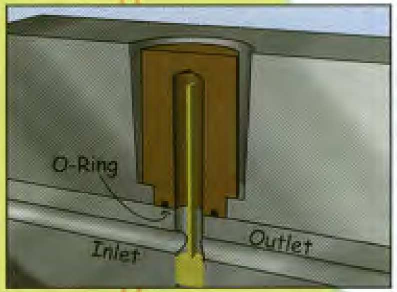


Illustration C: Self sealing core insert

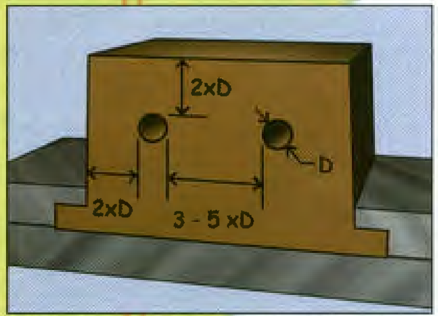


Illustration D: Heeled core with water passages

fer rates than steels (see Injection Mold Design Guidelines, number 1 for details) have proven over time to be the best choices for plastic forming mold components. Other copper alloys, including the aluminum bronzes, have attributes consistent with specific applications in the mold not associated with plastic forming. These include frictional wear and guiding surfaces where their excellent frictional properties can best be utilized.

Types of Core Construction

Mold cores can be machined from a solid mold "B" plate but are more commonly inserted into the "B" plate for ease of manufacture. When inserting the core, it is normally retained with a heel or cap screws. The heel on a core, see Illustration A, typically extending .125 for small cores and .250 for larger cores should have a length ratio of one to two times the heel for maximum strength. The corresponding counter bore is machined into the plate with clearance around the perimeter, allowing the main core body to align the insert. The depth of the heel pocket should match the insert to plus .0002 to insure that the core does not move in the molding cycle.

Other means of holding the core include blind pocketing, Illustration B, or self-sealing, Illustration C. The self-sealing insert is a popular choice for deep pocket inserting in applications where most of the part, outer molding surfaces, are formed on the "B" side of the mold. As the portion of the pocketed insert aligns the insert, the depth must be great enough to withstand any side pressures imposed in molding.

Tensile Strength

Tensile strength is extremely important attribute when selecting a suitable mold material. If there were a scale that measured toughness we would want to use that for a mold material. The copper alloys exhibit a good combination of tensile strength and ductility, making them tough and ideal candidates for mold components, not withstanding the high thermal conductivity properties. Tensile strength of the three copper alloys and three common mold steels are compared in the following tensile strength table.

Tensile Strength (ksi)			
Copper Alloy	ksi	Steel Alloy	ksi
C17200	190	H-13	206
C17510	110	P-20	146
C18000	100	420 SS	125-250

Mold Cooling

The injection molding cycle is made up of a number of elements. They include the filling portion, sometimes referred to as fill, pack and hold, the cooling portion and the mold open portion. The cooling portion is always the longest and frequently represents greater than 65 per cent of the overall cycle. Therefore, the longest element in the overall cycle is where the greatest benefit can be obtained in improving the injection molding cycle and where copper alloys work to your best advantage.

The principles of heat flow in an injection mold are: 1. Heat flows from the body with the higher temperature to a body of lower temperature (from the plastic to the mold component the plastic is in contact with). 2. The temperature difference, not the amount of heat contained, determines flow of heat. 3. The greater the difference in temperatures between the plastic and the mold component, the greater the flow of heat. 4. Radiation, conduction and/or convection transfer heat. Conduction is the main method of heat transfer in an injection mold.

The amount of heat that must be conducted from a mold can be calculated. It must be remembered that 65 to 75 percent of this heat must be removed through the core of the mold. The formula is as follows:

Where: H = Quantity of heat in Btu conducted

$$H=\frac{KAT\,(t_p-t_c)}{L}$$

K = Thermal conductivity factor of mold material in Btu/hr/ft2/°F/
A = Surface area of mold in contact in square feet
T = Time in hours
t_p = Temperature of plastic
t_c = Temperature of coolant
L = Distance from surface of mold to coolant channel

(Note: H-13, P-20 and 420 SS thermal conductivity ranges from 12 to 20, the three commonly use copper alloys range from 61 to 135)

The importance that the high thermal conductivity of properties of copper alloys has in removing heat from the mold can be determined from the formula. Obviously, the other elements of the formula are important considerations that must also be taken into account when designing an efficiently cooled injection mold. However, changing the mold material and the resultant thermal conductivity factor is normally the simplest and most effective means of achieving the best cycle time.

Coolant Options

The injection mold core is one of the more difficult areas to place and install t proper coolant channels due to the limited space available and ejection options necessary for part removal. It is important that the coolant system be one of the first considerations made in mold design, as the overall success of the mold project is dependant on how efficient the mold cooling cycle can be made. The use of copper alloys and their inherent superior thermal conductivity is the best guarantee the mold has at success.

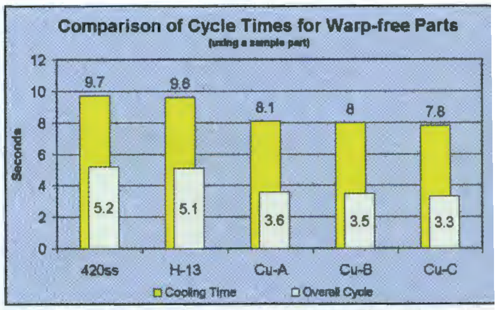
Copper alloys will insure that the surface temperate is as even as possible and will extract heat away from the plastic part. To maintain best operating conditions and short cooling cycles, it is imperative that the heat is efficiently removed form the molds core. Coolant lines, in the form of through-drilled channels or with the use of bubblers or baffles, should be installed in the mold core similar to a steel core. This will provide the best results and yield the most efficient cooling. Should the same coolant diameters and placement not be possible, the copper alloys are more forgiving than mold materials with lower thermal conductivity. Typically the copper alloys will allow greater liberties in placement of coolant channels, while cooling more efficiently than their steel counterparts. Caution should be used to insure that adequate provisions have been made for removal of the heat from any mold component.

If drilled coolant channels are machined directly into the mold core, the edge of the coolant channel should be about two times the diameter away from the molding surface. The distance between the coolant channels should be from three to five times the diameter, see Illustration D. Positioning the coolant channel any closer to the molding surface does not necessarily result in better cooling and in some cases provides a gradient differential in surface temperature, which could leave residual stresses in the plastic part. More details on cooling options will be presented in the sixth article in this series.

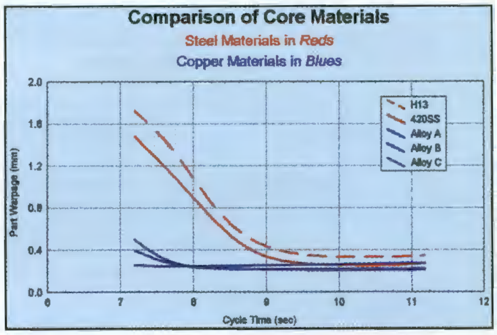
Cycle Time Improvements

Extensive testing was conducted at Western Michigan University comparing the use of the three most commonly utilized copper alloys in injection molds C17200 (A), C17510 (B) and C18000 (C) against H-13 and 420 SS. A single cavity test mold for a 50-mm polypropylene closure was obtained and optimized to run at the lowest cycle time possible. Identical mold components were fabricated from the three copper alloys and steel materials. Identical processing conditions were established and each core material was tested with the only variable being cooling time. Graph A illustrates the cycle advantages and the reduction in cooling times made by the copper alloys when compared directly to the conventional mold steels.

Each test was conducted after a controlled stabilization period. For purposes of evaluating the results of cycle time, cooling time was the only variable. The only mold change was the core itself. The only processing change allowed was to cooling time. Melt temperature, cooling temperatures, injection time, gate seal and other processing conditions were monitored to insure identical conditions. This test was perhaps the first time ever that exacting comparisons were made, under production type conditions, that physically demonstrated the advantages of the superior thermal conductivity and effects on the injection molding cooling cycle and the resultant overall molding cycle.



Graph A: Actual comparisons of best achievable cycle and cooling times in the same mold, the only change was the core material.



Graph B: Amount of part warpage lcompared to cycle time for copper alloys Vs tool steel.

Graph B compares part warpage, in millimeters, between the three copper alloys and two steel materials at various cycle times. The copper alloys remove heat so efficiently that part warpage is minimal, even at shorter cycle times. The benefit of improving part quality at faster molding cycles over steel is obvious. However, the greatest advantage might be the better consistency imparted into the plastic parts as a result of even mold surface temperatures.

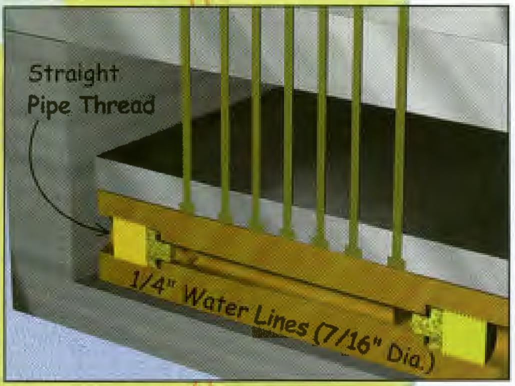


Illustration E: Chill plate application

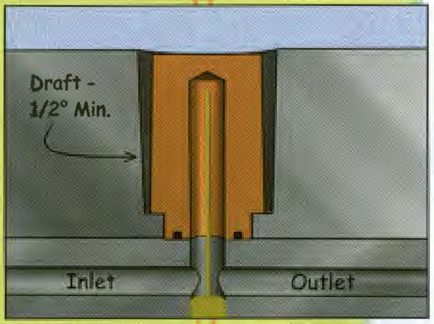


Illustration F: Self-sealing core with draft

This test was conclusive, confirming anecdotal experience from others where cooling cycle time improvements of 20 to 50 per cent are common on production molds when copper alloys are properly utilized.

Chill Plate Applications

Frequently molds with small diameter cores, those too small for cooling lines, benefit by seating copper alloy core pin heads on a copper chill plate of the same alloy. When ever core size or design allows you should install coolant lines using baffles, bubblers or drilled channels, to optimize mold cooling and temperature control. When either the number of core pins or the diameter prevents the installation of the coolant channels, the chill plate concept should be considered. Testing has found that the best results are obtained when the core pins and chill plate have the same high thermal conductivity numbers. Obviously the higher the thermal conductivity number the better. Coolant channels are installed directly into the chill plate to remove the heat and maintain the proper mold core temperature. In small diameter cores, where size limitations prevent water channel is the core, this concept has been shown to be almost as effective as cores with small coolant channels. The chill plate concept is not as effective as direct water cooling and should not be used for larger diameter cores where direct coolant is possible. Illustration E shows a chill plate application. Note, the chill plate can be installed under the main core or when using sleeve ejection, mounted to the back of the ejector housing.

Draft Considerations

The molded plastic part must be ejected from the core. To enhance part ejection draft, tapering of the part feature to assist in mold release is necessary. The draft angle specified should result after consultation with the plastic material supplier, plastic part designer, molder and mold designer. Draft should be as generous as possible and normally matches the draft on the cavity side to insure an even and consistent wall thickness, see Illustration F

Ribs on the other hand present a different problem. Large draft angles results in thick wall sections where the rib joins the main wall section. Normally, the junction of the rib to the wall should be one-half to two thirds of the mating wall thickness. The use copper alloys is of great benefit in these situations. The rapid removal of heat from the thicker ribs, due to the more efficient cooling of the copper alloys, will normally e reduce or eliminate the sink mark, which is typically caused by the delayed solidification of plastic at the junction of ribs at the wall of the part. Without the benefit of the superior cooling of the copper alloy, injection pressure and hold times are often extended. This not only results in longer cycle times but also increases the incidence of flash, warpage and over packing of the molded part. ❐

Acknowledgements

The injection mold design guidelines were written by Dr. Paul Engelmann, Associate Professor, Western Michigan University and Bob Dealey, Dealey's Mold Engineering, with the support of Dr. Dale Peters, for the Mold Marketing Task Group of the Copper Development Association. Kurt Hayden, graduate research assistant, WMU, generated the illustrations. Research conducted by WMU plastic program students.

Disclaimer

These guidelines are a result of research at WMU and industry experience gained with the use of copper alloys in injection molding. While the information contained is deemed reliable, due to the wide variety of plastics materials, mold designs and possible molding applications available, no warranties are expressed or implied in the application of these guidelines.

Contact Information

Information on copper alloys is available from the Copper Development Association, 1-800-232-3282.

Injection Mold Design Guidelines

THIRD IN A SERIES

Maximizing Performance Using Copper Alloys

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

The Injection Mold Cavity

A mold cavity forms the exterior of the plastic part and almost always is located on the "A" side of the mold. However, there are situations where the cavity is located on the opposite side of the parting line or occasions where the injection-molded part is symmetrical and the cavity is on both sides of the parting line. In these instances it is called a "B" side cavity.

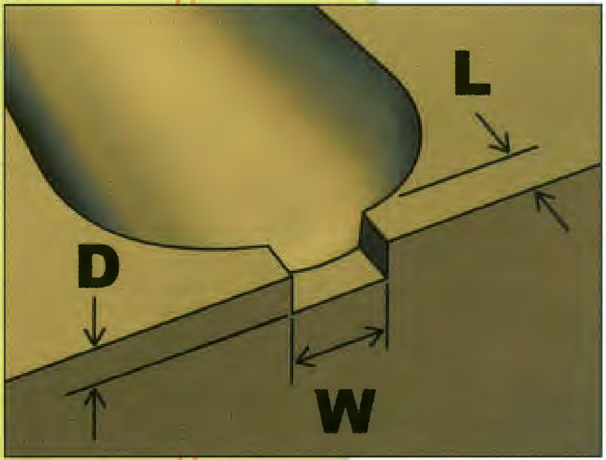


Illustration A: Edge gate showing gate width (W), depth (D) and gate land (L).

Cavity Inserts

Molds containing more that one cavity, multiple impression molds, are usually constructed individually, or if small, ganged into cavity blocks, and inserted into the mold "A" or cavity plate. Separate inserting allows for ease of manufacturing the cavity from a variety of mold materials and makes replacement easier should damage ever occur. Round inserts are a natural, as round insert pockets are easy to machine with great accuracy into mold plates. The round insert is an ideal application for "surround" cooling of the insert. "O" rings are used to seal the water channels and prevent coolant leakage. They should be designed to be placed in compression and not in shear, for ease of insert installation and leak free operation.

Mono Block Construction

Frequently in low run single impression and/or large molds the cavity is machined directly into the "A" plate. This type of mold construction is referred to as "Mono-Block" construction and eliminates the step of machining an insert pocket into the plate. Additionally, it offers a very rigid type mold construction with opportunities for excellent cooling channels surrounding the cavity.

Cavity Cooling

Cooling channels of appropriate diameter or channel size should be incorporated into the mold cavity block. Placement of these channels should follow similar recommendations made for the core of the mold. The coolant channel should be placed about two times the diameter away from the cavity with a pitch of three to five times the diameter. While it is common practice to run the cavity warmer than the core for aesthetic reasons, the best running molds are those where even surface temperatures and good temperature control can be maintained.

To insure turbulent water flow in mold cooling circuits a mold cooling analysis is conducted prior to mold building. This analysis checks and determines place-

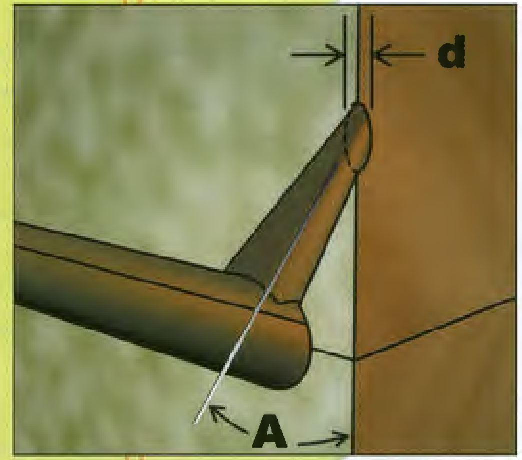


Illustration B: Submarine or tunnel gate, diameter and angle of cone illustrated.

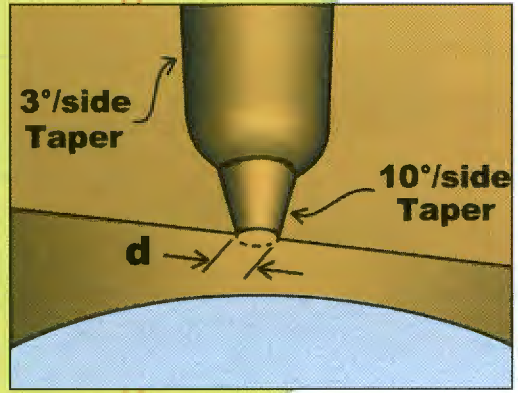


Illustration C: Pin point gate, used in three plate molds.

ment, number and size of coolant channels required. After the mold is built coolant flow can be measured to determine if adequate flow rates are being maintained. The following table lists pipe size and minimum amount of flow in gallons per minute which guarantees turbulent flow.

Nominal Pipe Size (NPT)	Channel Size (diameter)	Min. Flow (Gal/Min.)
1/16	.250	0.34
1/8	.313	0.45
1/4	.438	0.56
3/8	.562	0.75
1/2	.688	1.30

Core Inserts in Cavities

Holes in the part and other male core detail formed from the cavity side are normally achieved with core inserts in the cavity. Consideration has to be made for removal of heat from these components. Parts like television backs with air circulation slots are idea candidates for inserting high thermal conductivity copper alloys, C17200, C17510 or C18000 into the cavity, as are other hard to install coolant channels in other sections of the molds.

A pure mold cavity for an item like a drinking glass, where the plastic shrinks away from the cavity, only has to remove about 25 to 33% of the heat from the plastic. Plastic parts with contoured configurations such as toys sometimes are molded with 50% of the heat removed through the cavity. These parts benefit from the high thermal conductivity of the copper alloys and the more even mold surface temperatures offered.

Mold Base Materials

Additionally the mold plate can be build from the material most ideally suited for the type and amount of cycles the mold will run. The mold plates and/or mold base are normally built from 1030 plain carbon steel, Number 1steel for prototypes or very short runs. Number 2 steel, 4130-4140, is most often used for medium run molds. P-20 or Number 3 steel is used for long run molds and when part detail is machined into the mold plate. When a heat-treated mold plate is required, some cavity detail can be formed on the mold plate and the cavity built up with laminations, H-13 is a logical choice for these high run molds. Another material used for high volume and long running molds or with corrosive plastics is type 420F stainless steel.

Cavity Materials

When high thermal conductivity is required, either to more rapidly cool the plastic and promote faster cycles or to maintain a more even surface temperature for better dimensional consistency, the copper alloys designated C17200, C17510 or C18000 are used.

Gate Placement, Types and Size

Gate placement, normally in the cavity, is critical to the plastic component ultimate aesthetic and physical properties. The ideal location will, to a degree, dictate the type and size of the gate used for the mold. The best gate location, along with the type and size of the gate, is one of the early and difficult mold design decisions that must be made correctly to insure a good running mold.

In injection molding the more commonly used gates are the edge, submarine (tunnel) and pinpoint gate, which constitutes about 65% of molds built and which we will elaborate on. However, some parts are more ideally suited to different gate configurations including runnerless molding system drops, fan, tab, sprue, ring, diaphragm, flash and post gates.

Edge Gates

The edge gate is the most common type of gate on conventional molds. (Illustration A) Typically, the gate depth (d) is 50 to 80% of the wall that it is connected to. The depth of the gate controls gate freeze off and is the most critical dimension in determining pressure loss. Width of the gate (w) is generally two to four times the depth, depending upon the volume of plastic required to fill the part. The gate land (l) should be short to avoid large pressure losses. Additionally, a short gate land will assist in breaking or degating the part from the runner.

Submarine Gate

The submarine (frequently referred to as a tunnel or sub) gate is a popular choice on conventional molds when an automatic method of separating the part from the runner system is desired. The diameter of the gate (Illustration B) is generally 50 to 70% of the wall section, with 60% a common choice. The angle of the cone is normally 30°. However, with stiffer materials it frequently is less. Care must be taken so as not to place the cone too close to the cavity thereby avoiding thin cavity material sections and premature failure. Flexible plastics allow the angle to increase, as the plastic will still pull from the cone. Most submarine gates are placed to enter on the cavity side of the mold. In these situations, ejector pins with pullers are incorporated in the runner system to hold the runner during gate separating and then eject the runner.

Pin Point Gate

Pin point gates (top gating) are used in modified and three plate molds. Typically, and almost without exception, round parts like closures and caps have the gate located in the center of the part. The cone, connecting the runner system with the gate starts with a full radius at the end and typically has a 2°-3° angle to assist in extraction with the assistance of a sucker pin. The gate portion tapers down at about a 10° angle. The intersection of the gate to the cavity must be sharp providing for a good break off. Generally, the amount of gate projection from a pin point gate is one-half the gate diameter. The gate diameter (Illustration C) is 30 to 60% of the wall that it is connected to. The ideal gate diameter is a function of the flow properties of the plastic; the easier the flow the smaller the gate diameter. The harder the flow, the larger the diameter. Obviously, the smaller the gate diameter the better the cosmetics on the part and the smaller the gate vestige.

The ideal location for the gate is listed below. Unfortunately, sometimes trade offs must be made and not every criteria can be satisfied. Therefore, a decision has to be made as what is the best compromise in gate placement. 1. Plastic must have the ability to fill the entire part without using extreme processing conditions and maximum injection pressures. (Multiple gates may be required on some parts) 2.Material, flowing from the gate, will push gasses toward the parting line or other areas where they can be effectively vented and will not entrap gas. 3. Plastic will flow into the thickest section of the part and will flow from thicker to thinner sections. 4. Flow to all points on the part will be of equal distance and the part will not experience areas of over packing. 5. The gate must be located in an area not subjected to high stresses (the gate area could well be the weakest section on the part). 6. Plastic entering the part from the gate must impinge on a wall or mold member to create a small back pressure, avoid jetting. 7. The location has to be in an area that will minimize weld, flow or knit lines especially on class "A" surfaces. 8. The gate mark should not be located on an appearance or functional surface. 9. If the gate is of the type that must be trimmed, it must be located in an accessible area.

Methods of Venting

Injection molds must be vented to allow volatiles released from the plastic pellets during the plasitification process and the air trapped in the closed mold to escape. Adequate vents must be installed on the parting line, runner systems and in any place in the mold where entrapment of these gasses occur. The depth of the vent must be less than that which the plastic will flash. Experience has proven that the location of the vent in proximity to the gate will determine the depth to which plastic will flash. The closer the vent is to the gate the easier the material will flash. The longer the flow distance from the gate, the less likely plastic will flash at the same depth. Information available from the plastic material supplier is a very reliable source for technical information.

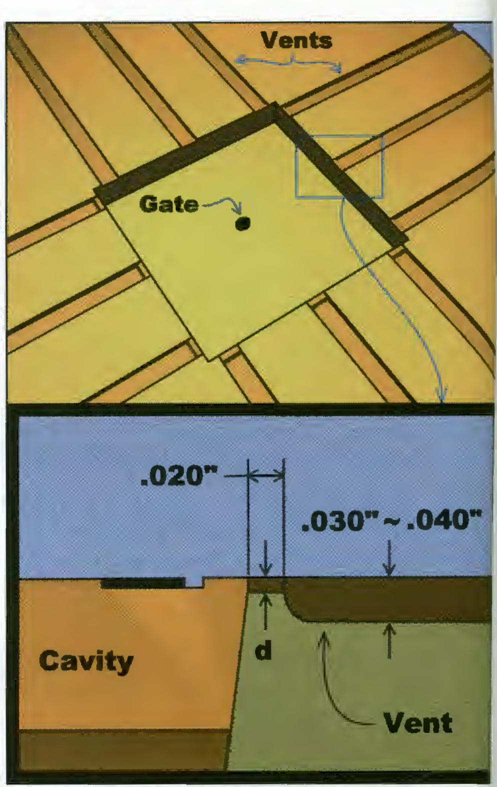


Illustration D: Venting of mold cavities, upper view showing vents bleeding to outside of mold. Lower view illustrates typical dimensions for vent and bleed off.

Vents

Vents (Illustration D) should be installed at the mold parting line. The depth should be slightly less then where flash will form. Vents should be 1/4 to 1/2 inch in width. After a short land length, typically .020 inch, the vent depth should be machined .03 to .04 deep and must lead to atmosphere outside the mold. Conventional runner systems should be vented also. Any gas that can be vented prior to arriving at the cavity is less volume that has to be allowed to escape. Typically runner system vents are twice the depth as the part if runner flash is not an issue and installed at the end of the runner and at junctions. Stopping short of the outside of the mold with any vent is extremely inefficient in allowing gasses to escape and considered bad practice.

Round parts with top gates, (Illustration E) lend themselves to relief around the entire part. A collector ring assists in collecting

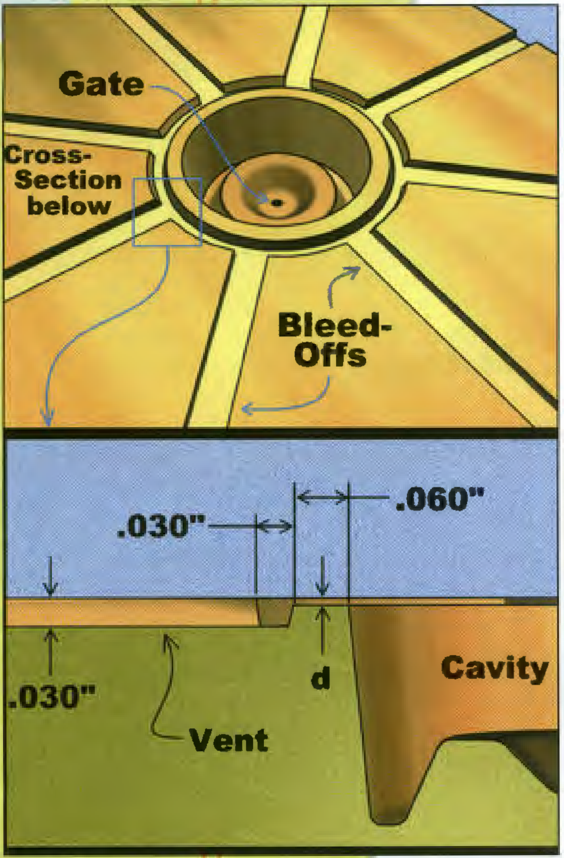


Illustration E: Top view shows perimeter venting of round cavity. Bottom view illustrates the vent and bleed off, typically used in relief venting.

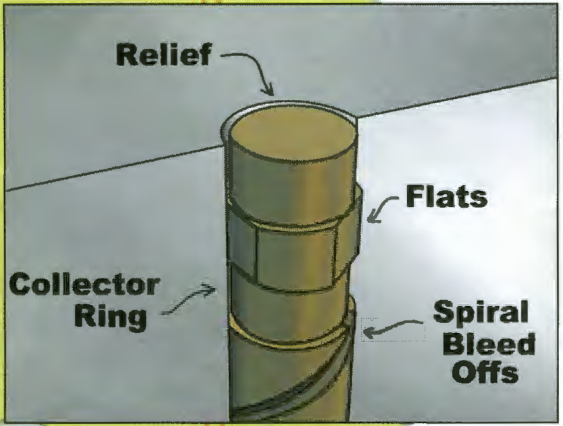


Illustration F: Method of venting at ejector or core pins.

the gasses and bleed offs allow them to escape to atmosphere. The volume of the bleed offs must equal or be greater than the volume of the collector rings to be efficient.

Areas in the cavity that can be vented other than the parting line are at insert lines, core pins and areas where sintered vents can be installed. Ejector pins are often overlooked as excellent places to install vents, as they are self cleaning due to their movement at ejection. An effective vent can be achieved by grinding relief on the top diameter (Illustration F) to allow the gasses to escape around the diameter to a collector ring and then spiral bleed offs to the ejector housing. This method keeps the ejector pin centered in the ejector pin hole, preventing shifting of the pin causing flash on one side of the pin and shutting off the vent on the other side and is much more effective than an undersize pin in an oversized ejector pin hole.

Mold Finish

The Society of Plastics Industry (SPI) developed and publishes a standard for mold finish that is universally used to specify the desired effect on the plastic part. The standard is based on four different methods, polishing with diamond, paper, stone or blasting. These categories then have three subgroups defining the last benching or polishing operation that will yield the desired finish or appearance on the plastic part. In addition to the listing of the SPI finish standard number and the corresponding operation, we have included the Ra and RMS measurement taken from a finished component. It is important to remember that the measurement is not part of the SPI standard, nor is it endorsed by SPI. It is simply included as a reference.

SPI Finish	Definition of Last Operation	Ra	RMS
A-13	Diamond Buff	0.6	0.8
A-26	Diamond Buff	0.8	1.0
A-315	Diamond Buff	0.9	1.2
B-1600	Grit Paper	2.1	2.6
B-2400	Grit Paper	3.8	4.9
B-3320	Grit Paper	4.8	6.2
C-1600	Stone	4.4	5.7
C-2400	Stone	8.0	10.2
C-3320	Stone	8.9	11.4
D-1	Dry Blast # 11	8.8	11.1
D-2	Dry Blast # 240 Al Oxide	13.2	17.0
D-3	Dry Blast # 24 Al Oxide	80.8	104.5

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Injection Mold Design Guidelines

FOURTH IN A SERIES: Nomenclature

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

Maximizing Performance Using Copper Alloys

Nomenclature for the types of molds is somewhat diverse but usually follows an order describing the type of runner system, mold action and ejection method used. A mold is considered a standard mold when it has a conventional runner system, the part is pulled without any action and the mold only has an opening at the parting line. Occasionally we hear the term two-plate applied to this type of conventional mold. This is not necessarily a correct description and perhaps is only used to differentiate it from a three-plate mold.

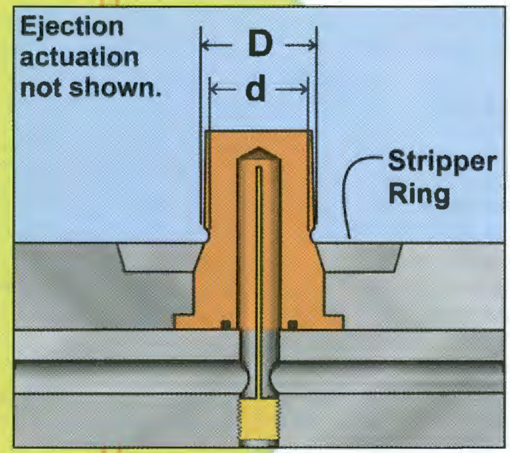


Illustration A: Stripper ring ejection of an undercut.

A three-plate mold has the runner system installed between a separate parting line and the parts are gated with a pin point gate. The advantage is that the cold runner is separated from the parts on mold opening. This type of mold was popular for top gating parts and now frequently a runnerless molding system is used in its place.

Runnerless molding systems (RMS) account for nearly 30% of the molds built today. RMS can be internally or externally heated. If internally heated, the mold has distributor tubes and/or probes with electric heaters placed in the distribution channels to maintain the melt temperature of the plastic as it flows around the tubes toward the gate. Each cavity needs at least one probe to feed plastic for the mold to be a true runnerless molding system. Often hybrid systems are used, especially on small parts where one probe is used to feed a conventional runner system, which then feeds multiple parts. Copper alloy probes have proven to hold more even temperature profiles than steel alloys, especially at the tip end.

Internally heated systems incorporate a manifold with balanced and streamlined passages installed for the plastic to flow from the inlet to the nozzles. Nozzles normally equipped with coil heaters around the periphery and a thermocouple to control the temperature, feed plastic from the manifold to the gate. A very popular divergent flow style incorporates a copper alloy tip, usually made from C17200 or C18000 copper alloy, to aid in maintaining an even temperature profile at the gate entrance to the cavity. The melt flow typically diverges from the center flow passage through orifices allowing the copper alloy tip to extend down to or into the gate orifice. The tip then maintains control of the gate area, freezing the gate during part removal and maintaining the correct temperature to open the gate for the next cycle.

Molds can have many actions, depending on what has to be accomplished, to free undercuts and remove the part from the mold. External threads for example, if not strippable, utilize slide action or expandable cavities to free external features.

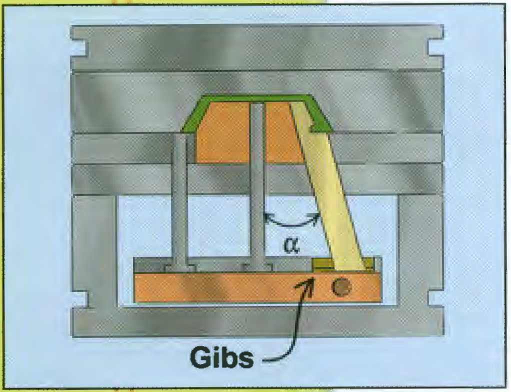


Illustration B: A lifter shown with the mold closed. Lifter angle is exaggerated, should not exceed 5°.

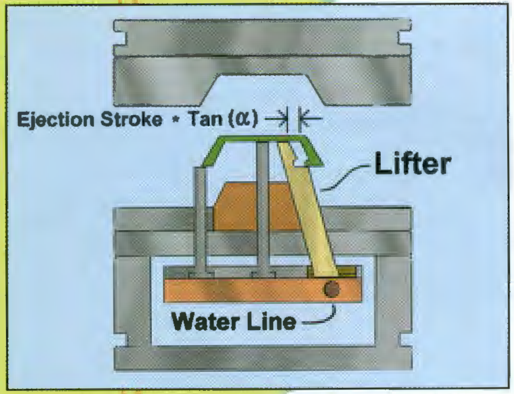


Illustration C: Lifter actuation shown during ejection. Lifter angle is exaggerated, should not exceed 5°.

Internal threads can be formed on collapsible cores or in unscrewing molds. Several methods are used for unscrewing molds, including hydraulic motors, splines, various gearing methods and for large multiple cavity molds, racks and pinions are used.

Other mold actions include lifters, wedges or slifters (a new term), raising members and slides (sometimes referred to as splits, cams and side action). Mold nomenclature then typically describes the type of ejector system used, normally ejector pins, sleeves, stripper rings or plates. Therefore, molds are normally refereed to as "a three plate, slide action sleeve ejected mold", or "runnerless collapsible core, stripper plate mold".

Mold Slides

Undercuts, features on the plastic part that are not in line with normal mold opening, are frequently encountered. When the undercut is small, typically defined as a percentage of the overall part dimension, the best and least expensive option is to determine if the part will flex enough to strip off the cavity or core without the use of a mold action. Freeing the plastic undercut is first dependent upon the plastic material, its flexibility and hardness. The greater the flexibility and more compressive the plastic the greater the undercut can be. The stiffer and more rigid the plastic material, the less the undercut must be. Undercuts are defined as the percentage difference between "d", the amount of the undercut, and "D" the diameter or dimension that the undercut has to snap off (see Illustration A).

Seals are molded from flexible PVC with undercuts greater than .375 inch and a 1.500 diameter, resulting in undercuts of 25%. Modified Closure Manufacturer's Association (CMA) threads are frequently stripped on closure sizes above 24mm in polyethylene and polypropylene, especially in co-polymers. Acme or buttress threads typically will not strip due to the sharp and flat thread profile perpendicular to the direction of draw.

External part features, those normally found on the cavity side of the mold, require that the core be removed prior to attempting to free even the slightest undercut, as the flexing plastic must have a place to compress or expand into if the part is manufactured without moving mold members. When the undercut is too great, the mold cavity can be split or moving cams installed to release the undercut. These plastic part features with details connected to the main wall tend to have the thickest sections. Copper alloys with their ability to cool faster than conventional mold steels have proven to be the best choice of mold materials in these areas. Copper alloys will provide the most even surface temperatures necessary to take the heat away from the molding surfaces. Frequently, the front of the slides are faced or inserted. A copper alloy is inserted on a steel slide carrier and coolant channels are machined through the carrier into the copper alloy insert. With this design, the copper slide face acts as a watered heat sink, drawing heat away from the part.

In all other designs the slide should be designed with the same concept and mold coolant channel as the molds cores and cavities. The coolant channels could include looping flow, baffles or bubbles. A coolant-circulating cascade is available from a number of standard mold component supplies and is ideal for getting coolant into hard to reach areas like those found on a slide. The best practice is to place these coolant lines about two diameters of the cooling channel away from the molding surfaces. This standard works well with the copper alloys, as well as mold steels. However, if you cannot get that close to the mold surface, the more efficient copper alloys, with their higher thermal conductivity, will perform well when the coolant lines are not ideally located.

Mold Lifters

A lifter is a component in the mold that is normally attached to and actuated by the ejector system and moves at an angle to free internal molding detail (see Illustrations B and C). They are typically attached between the ejector retainer and ejector plates with some mechanism allowing the fixed end to slide or pivot to compensate for the movement of the lifter position as it moves at the desired angle. Lifters are frequently used when segmented plastic undercuts (raised mold core detail) is necessary. The lifter has to move out of the mold core at an angle, typically 5° or less, to clear the plastic from the mold lifter detail. This angle is critical for two reasons. First, if the angle were too great the forward motion of the ejector system would put too much pressure against the lifter body. This pressure would create binding of the lifter and lead to excessive wear or premature failure. Should the angle be too shallow, the ejector plate travel would be excessive. Therefore, careful engineering and good judgement has to be made.

Due to their function, lifters are normally long and narrow. Coolant channels are nearly impossible to machine into them. The C17200, C17510 and C18000 copper alloys, normally used in the mold cavity and core, will remove the heat efficiently from the lifter. However, because this is a high wear area and when the mold core is built from one of the alloys already, aluminum bronzes make excellent choices for lifter materials. More information on aluminum bronzes will be included in article eight of this series. To avoid seizing the lifter, one copper alloy riding against another copper alloy is not good engineering practice. One of the components should be plated or coated. The plating or coating should be carefully chosen, as it must provide a low coefficient of friction between the two surfaces. Surface treatments should provide dry lubrication and not be affected by contact with the plastic material and thermal cycling of the mold component due to the molding process.

As the lifters have to move inward from the inside wall of the plastic part to free the undercut, the part must be devoid of any detail that would prohibit or impede lifter movement. Should the part design not allow this required movement the only choice to form this part detail may be with the aid of internal or hidden slides. The problem with internal slides is the amount of room they take to position and move them in a core.

Wedges or Moving Members
Wedges are mold components that have a shape that allows them to fit tight in the molding position but when moved forward free themselves from the pocket to move away from the plastic wall (see Illustrations D and E). They have a guiding system allowing them to move forward and away from internal or external undercuts on the plastic part. The wedges are normally located on the "B" side of the mold and are either pulled with a mechanical attachment from the "A" side of the mold, or pushed by the ejector system or cylinders. While less common, wedges can be installed on the "A" side of the mold.

The wedge must be guided as it moves forward. The two guide systems most frequently encountered are the "T" slot or dovetails. Molds with wedges utilizing dovetails to guide and hold the wedge in position are being called "slifters" in the tooling community. Wedges or slifters have a commonality with lifters. The angle in which they raise must be steep enough to free the undercut within the movement range and yet shallow enough so as not to bind or be exposed to conditions where excessive wear could occur.

By design, these mold members have large areas in contact with the plastic part. Therefore it is necessary to build them with coolant channels and from materials with high thermal conductivity rates. While these wedges and slifters are ideal candidates for the C17200, C17510 and C18000 copper alloys for the plastic forming contact areas, they are not the best choices for the "T" or dovetail guiding systems. Therefore, several options should be considered in their construction. One preferred method is to laminate hardened tool steel to the copper molding face and install the guiding system in the tool steel. Aluminum bronze materials can be laminated to the opposing member of the mold to reduce friction and avoid common tool steels acting as bearing surfaces.

Raising Mold Members
Occasionally plastic parts will have extreme contours. Automotive "A", "B" and "C" pillars, for example, which have geometry where the only way to free the part is to raise it out of the mold and physically or mechanically flex the plastic to remove it from the mold core. These molds are frequently considered raising core molds. This type of arrangement complicates the installation of coolant channels due to their contour and shape. Placement of the coolant channels can be far from ideal. Typically a tool steel core member in these applications results in areas where cooling is compromised. Copper alloys have proven time and again that they will, due to their high cooling rates, run cooler and have more evenly distributed surface temperate than a steel counterpart would have. The plastic product almost always has less warp, twist, sink and is more dimensional consistent, due to improved temperature control of this raising mold member.

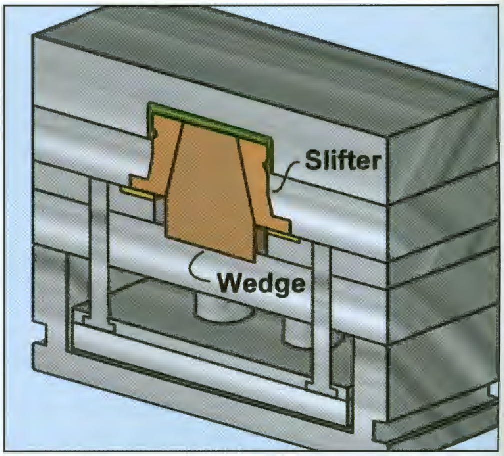


Illustration D: Wedge/"slifter" with the mold closed.

Other Mold Movements
The injection-molding machine provides one movement when the machine platens separate. The subsequent mold opening provides the mold designer with motion that can be used to mechanically create movement in another plane. Plate movement, commonly referred to as floating of the plates, creates the conditions where the desired mold actions can be incorporated.

One example is the movement of conventional mechanical slides on the "B" side of the mold with an angle pin (see Illustration F). The angle pin(s) is located on the "A" side of the mold and when the parting line separates the pin, due to the angle, moves the slide out. If the same movement is required on the "A" side of the mold the problem of clearing the undercut prior to the main parting line must be overcome. One solution may be to pull the slides with hydraulic or pneumatic cylinders prior to the mold opening. If the slide has plastic forming projected area against it the cavity pressure must be overcome by some locking method.

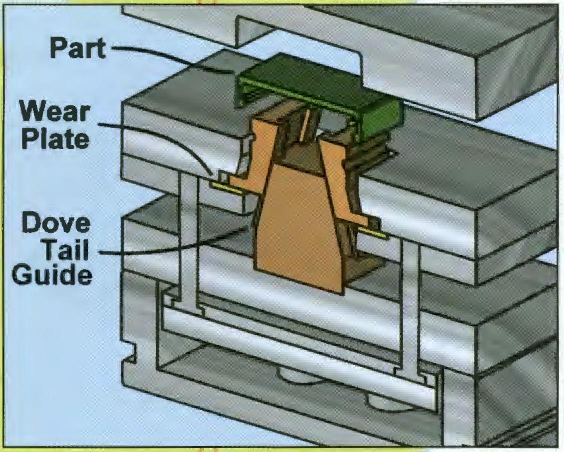
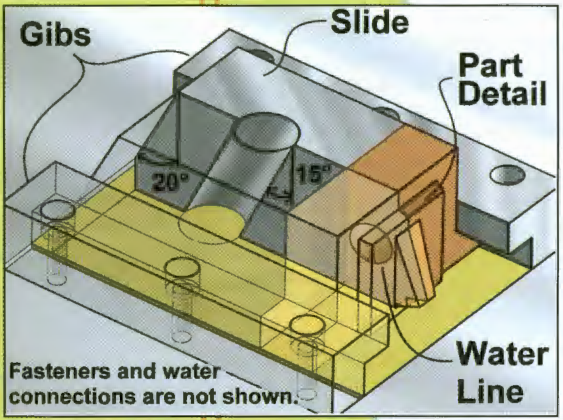


Illustration E: Slifter actuation during ejection, showing the wear plates and dove tail guides.



Fasteners and water connections are not shown.

Illustration F: Copper faced slide showing the use of an angle pin. The cooling circuit path and "O" rings between copper and steel are not visible in this view.

Should the area and pressures be small the cylinder may have enough force to prevent movement. If the pressures are great, then a locking cylinder must be used. In any event, the timing of the cylinder retraction and advancement must be tied into the molding machine and measures taken to insure that the slide is in the proper position on mold opening and closing.

To move the "A" half slides mechanically a mold movement has to be established where the "A" plate floats (retaining the plastic part) creating forward movement so that angle pins mounted in the top clamp plate can actuate the slides away from the part and clearing the undercut. Once the part is clear from the slide the plate movement is positively stopped, normally with shoulder or stripper bolts, and the main parting line is allowed to open.

The movement of plates is typically accomplished with a puller mechanism. Frequently external mounted commercially available latch lock devices are mounted on the mold. These mechanisms are solidly attached to the mold member that will be actuating the plate and the opposite end of the device will contact and lock the plate when moving it and release when the desire travel has been reached.

Timing

The expression used to describe the proper sequence of events in mold action is timing. The opening and closing of a standard mold is straight forward, the sequence of events is that the mold closes, plastic is injected, the plastic is cooled, the mold opens, the parts are ejected and the cycle continues. When mold actions, items like slides, lifters, wedges, floating plates, etc. are incorporated, the sequence of events must be pre-determined and the mold designed and built to insure that the proper event happens and that the plate or movement has traveled the correct amount prior to the next sequence starting. Additionally, it is important that the mold actions return in the proper order. Over the years, almost any action or movement has been installed in production molds. We are only limited by our imagination on how to positively insure that the proper mold action will take place at the correct time and then reverse the process to prepare for the next molding cycle.

There is no room for error in sequencing of mold actions. Each operation must be precisely carried out in the proper sequence with the movement required exactly carried out. If any plate or action is left to chance, damage will occur sometime during the molding run. The correct way to design the mold is to positively achieve the desired movement at the right time, while providing a method of determining that the sequence has occurred prior to allowing the mold process to continue to the next step. ■

Acknowledgements

The injection mold design guidelines were written by Dr. Paul Engelmann, Associate Professor, Western Michigan University and Bob Dealey, Dealey's Mold Engineering, with the support of Dr. Dale Peters, for the Mold Marketing Task Group of the Copper Development Association. Kurt Hayden, graduate research assistant, WMU, generated the illustrations. Research conducted by WMU plastic program students.

Disclaimer

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Contact Information

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Injection Mold Design Guidelines

FIFTH IN A SERIES

Maximizing Performance Using Copper Alloys

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

Copper Alloy Core Pins

The fastest, easiest and quickest method of proving benefits from the high thermal conductivity properties of copper alloys is to replace a core pin in a troublesome application. Core pin, as the name implies, forms the interior of a plastic part feature. Problem areas in the mold that will benefit from the core pin replacement include heavy wall sections that control cycle time, interior part features that cannot be cooled efficiently, sections prone to sink marks and features that require tighter and more consistent dimensional control. (Illustration A)

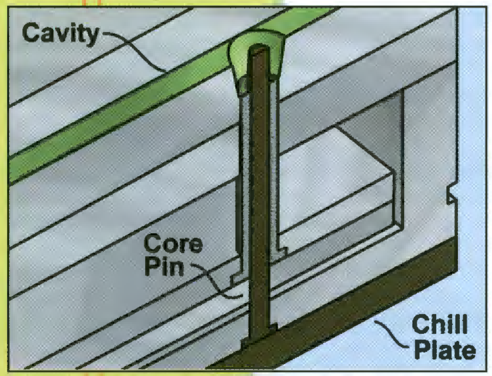

Illustration A: Core pin forming a hole in the plastic part. The core pin transfers heat to a chill plate for faster cooling cycles.

The principles of heat flow should be understood and applied in the injection mold design as the mold acts as a heat exchanger during the molding cycle. Those principles are: 1. Radiation, conduction and convection transfer heat. (Conduction is the main method of heat transfer in a mold and is the most efficient means of cooling) 2. Heat flows from the body with the higher temperature to a body of lower temperature. (You cannot transfer cold). 3. The temperature difference, not the amount of heat contained, determines flow of heat. 4. The greater the difference in temperatures between the bodies, core and plastic, the greater the flow of heat. 5. The thermal conductivity of the mold materials will have a dominant affect on the amount of heat energy transferred.

The following mold-cooling formula is normally used for engineering mold designs for efficient operation:

$$H=\frac{KAT\ (t_2-t_1)}{L}$$

Where:
H = Quantity of heat in Btu's Conducted
K = Thermal conductivity factor of mold material in Btu/hr/ft2/∞F/ft
A = Surface area in contact with the plastic part in square feet
T = Time in hours
t_2 = Temperature of injected plastic
t_1 = Temperature of circulating medium
L = Distance from the plastics surface to the circulating medium

It is apparent from this equation that to remove Btu's more rapidly the mold design should use materials with the highest thermal conductivity (copper alloys, C17200, C17510 and C18000 have six to nine times greater thermal conductivity than conventional mold steels). The lowest temperature possible of the circulating medium is a good option. However, especially with semi-crystalline materials, mold temperatures cannot be extremely low or the proper formation of the crystalline structure will not be formed in the plastics. Basically it is not possible to increase the area in contact with the core pin and increasing "T", the cycle time, is opposed to our objective of achieving the shortest possible cycle time.

Copper alloy core pins are then ideal for use in cooling plastic in a mold as they are in contact with the plastic and will remove heat by conduction. The copper alloy core pin can transfer heat rapidly to an area of cooler temperature, insuring flow from the plastics through the core pin, due to the greater temperature dif-

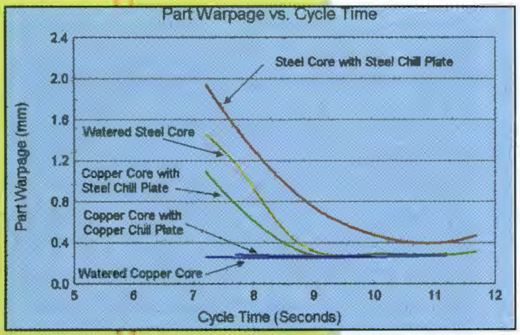

Chart B: Chart illustrates advantages of copper alloys in reducing part warpage and cycle times.

ference between them. The fit dimensions and tolerances of core pins are critical to the success in their function in the injection mold. Core fit at its mounting surface, is typically an interference fit of -.0000 to -.0005 depending on its size and frequency of removal from the mold. As a general rule the length of the fit area should be at least twice the diameter.

As the core pin forms its detail in the surrounding plastic, the heat given off from the plastic must be absorbed and transferred through the core pin to an area of the mold where the heat can be transferred into cooling lines. As with tool steel cores, the most efficient method of removing the heat is with an internal coolant passage with cooling medium circulating in the core itself.

Mold Material and Description	Coefficient of Thermal Expansion 10-6/F	Applications in Molds
420 SS Stainless Steel	6.1	High Gloss Cavities
H-13 Tool Steel	7.1	Hardened Cavities and Cores
P-20 Tool Steel	7.1	Pre-Hard Cavities
C17200 2% BeCu	9.7	Cores, Core Pins, Cavity Inserts, Slides, Etc. Where Higher Hardness is Desired
C17510 .5% BeCu	9.8	Cores, Core Pins, Cavity Inserts, Slides, Etc. Where Higher Thermal Conductivity is Desired
C18000 CuNiSiCr	9.7	Cores, Core Pins, Cavity Inserts, Slides, Etc. Where Higher Thermal Conductivity is Desired
C62400/C95400 Al Bronze	9.0	Lifters, Bushings, Bearings, Wear Plates, Gibs and High Wear Areas
C62500/C95900 Al Bronze	9.0	Ejector Sleeves, Bushings, Bearings, Wear Plates, Gibs and Load Bearing Areas

Illustration C: Chart listing various mold materials, coefficient of thermal expansion and applications in injection molds.

Tests at Western Michigan University have proven the effectiveness of transferring heat from the plastic through a copper alloy core pin and then into a copper alloy chill plate. (Chart B). In this illustration, the results of exhaustive testing in the same mold are shown; steel and copper core pins with and without water circulating in them were tested. The tests prove the effectiveness of core pins made from copper alloys, with higher thermal conductivity rates than tool steels, will cool a part faster with far less warpage at shorter cycle times than their steel counterparts. Note that the warpage of a part molded with copper alloy core pins, resting on a copper alloy chill plate, had less warpage than the part molded with a steel core with water circulating, even at a 22% longer molding cycle.

From the Western Michigan University test data one can conclude that "L" is rather insignificant when the combination of the copper alloy core pins and chill plate of the same material and thermal conductivity is used in a mold design. This is an important discovery and technology improvement in the efficiency of mold building and injection molding.

Coefficient of Thermal Expansion

The coefficient of thermal expansion must be considered when designing molds with materials that expand at different rates. The degree of thermal expansion is critical in both the fit of the components and the correct dimensions to design and build the mold core, components and cavity. Copper alloys have larger expansion coefficients than tool steels and are listed in Illustration C.

Both the plastic material shrink rate and thermal expansion of the mold cavity and core must be taken into consideration in the design of close tolerance molds. Plastic shrink rates, when using copper alloys in the mold, may be reduced when compared with steel components. If the plastic material shrink rate is affected by mold temperature, then compensation must be made. Typically, the mold surface temperature will be more consistent and lower with the use of copper alloys. If the mold will be run at elevated temperatures, as is the case with many of the new engineering grades of materials, the thermal expansion of mold cavities and cores must be considered when specifying mold sizes. This same consideration should be taken into account when inserting a copper alloy into a steel retainer. The final fit should be calculated at operating temperatures.

Ejector Sleeves and Core Pins

Core pins fitting into ejector sleeves requires special considerations. Standard off the shelf ejector sleeves are built to accept pins with tolerances applicable to ejector pins and not core pins. Apparently when ejector sleeves were first introduced the only close tolerance pins available were ejector pins and the precedent was established. As ejector sleeves are utilized to force plastic off mold detail, it implies that a core pin should be used in the application. The core pin must rapidly transfer heat removed from the plastic to another part of the mold. The high thermal conductivity of copper alloys performs this function efficiently and results in a very consistent and uniform shot-to-shot component temperature.

Care must be taken to provide the proper clearance between the ejector sleeve and copper alloy core pin. Always check your ejector sleeve supplier's dimensions and tolerances, the ejector sleeve has an internal tolerance of the nominal dimension + .0005 -.0000 inches. The copper alloy core pin should have approximately .0010 to .0015 clearance, depending upon the diameter and at what clearance plastic will flash. Copper alloy core pins can not just automatically be used with standard ejector sleeves as the tolerances do not allow enough clearance and galling of the components will result. Proper consideration must be made in providing the proper sliding fit.

The other design necessity is to insure that the proper bearing length between the ejector sleeve and core pin is used. (Illustration D) Bearing length should be a function of the core pin diameter. The general rule of thumb is that the bearing length should be two times the diameter. We think when the bearing length exceeds one-half to three-quarters of an inch, problems will occur as a result of too great of a bearing length. Experience in the mode of failure between the sleeve and pin show that 90% of the time the bearing length is too long. Standard ejector sleeves are provided will allowances for cutting to the desired length and the bearing length is purposely long to accommodate all possible sleeve lengths in that size range. Therefore, when the sleeve is cut for just a short length, the bearing length is long and that is generally when problems occur.

Copper Alloy Ejector Sleeves

Thin wall ejector sleeves built from C65900 aluminum bronze and then plated are successfully utilized in high speed and high cavitation unscrewing molds. The sleeves offer advantages over their H-13 counterparts as they provide an extremely low coefficient of friction. More importantly, they hold their roundness better in thin wall sleeve applications. Diameters of 2.000 inch with wall thickness of .040 inch in the ejection area have been known to run 1,000,000 cycles. When the plating begins to show evidence of wear or exposes the copper alloy, the mold components are stripped, refit and plated again. Due to similar materials, it typically is not a good practice to run copper against copper in ejector sleeve applications. However, with the proper plating on both components, success has been achieved in high volume molds.

Copper Alloy Ejector and Sprue Puller Pins

The placement of ejector pins, sleeves, rings or bars in the mold is crucial to the efficient removal of the plastic part. First and foremost, the ejector component must push the plastic off the mold member. Placing an ejector pin on a surface that creates a pulling action on a plastic wall results in greater resistance to the removal of the part.

Ejector and sprue puller pins built from the copper alloys, C17200, C18000, C62400 and C62500 are successfully used in high volume molds. The copper alloy ejector pins require slightly greater clearances between the pin and the ejector pinhole to compensate for their higher thermal expansion. These pins work well when additional heat must be taken away and have proven beneficial when used in thick wall applications for reducing or eliminating sink marks.

One of the most impressive success stories involves the use of a copper alloy sprue puller pin. (Illustration E) Problems are frequently encountered in cooling the sprue puller enough to efficiently pull the sprue. The use of the copper alloy sprue puller is highly effective and recommended when flexible materials are molded and problems pulling the sprue are encountered. Again, the bearing length on the sprue puller pin should be two times the diameter of the pin.

The most common mode of failure of an ejector pin is galling created by overly long bearing lengths. This failure mode is typically observed when a tensile failure occurs. (Illustration F)
Buckling of ejector pins is the second most common mode of failure.

When small diameter pins are used, whether in steel or copper alloy, stepped ejector pins should be used for maximum resistance against bending. Euler's Formula for long and slender columns can be used to determine how long an ejector pin can be in relation to its diameter. Most ejector pin failures occur, due to the column being slender where bending or buckling action predominates over compressive stresses.

Ejector Rings, Bars and Air Poppets

When concerns regarding wear of ejector components are encountered, copper alloy stripper rings or bars can be used. The ductility of the copper alloys, along with the low coefficient of friction between them and tool steels make them ideal candidates for these mold components. Stripper rings inserted into guided steel stripper plates designed with minimal clearance results in long maintenance-free operation. In the event of the plate cocking or shifting of the core, damage to the expensive mold component can be minimized with the use of the copper alloys. Additionally, the hard-to-cool area of the stripper plate contact surface is accommodated nicely by the high thermal conductivity of the copper alloys.

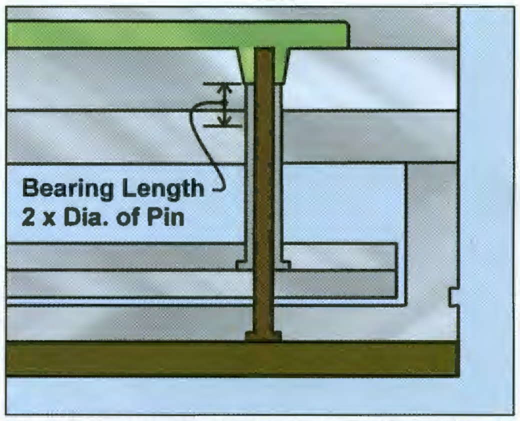

Illustration D: Bearing length of ejector sleeves should be no greater than two times the diameter.

Ejector bars, similar to ejector rings but straight, are being used to contact long wall sections and are replacing the large number of small diameter ejector pins commonly used. This concept, using the low friction properties of the aluminum bronze copper alloys, provides a robust means of ejecting on large surface areas. Fewer ejector pin impression marks are encountered at shorter cooling and cycle times with the use of ejector bars.

Head Clearances for Ejector Sleeves and Pins

To allow for any misalignment in machining of the multiple plates in the mold and to compensate for any adverse thermal expansion, clearances must be provided for the ejector components in the mounting area. The counter bore depth in the ejector retainer plate for the sleeve or pin head should be .001 inch greater than the actual head dimension. This allows the fixed end of the column to seek its proper alignment in relationship to the corresponding hole in the mold core.

The head counter bore diameter should be .015 inch larger than the sleeve or pin head diameter. Through clearance in the ejector retainer plate for the sleeve or pin shank should be .005 inch. These clearances will hold the head end of the ejector component secure, yet allow enough movement to not create binding when the device tries to seek its own location.

Clearances through the support and "B" plate should be .032 inch greater than the ejector component diameter. Each plate leading edge should be countersunk with a 45 degree taper for ease of assembly and to prevent damage to the outside edge of the ejector component. The mold should be assembled with the ejector plate separated from the ejector retainer plate. Each ejector sleeve or pin should be indi-

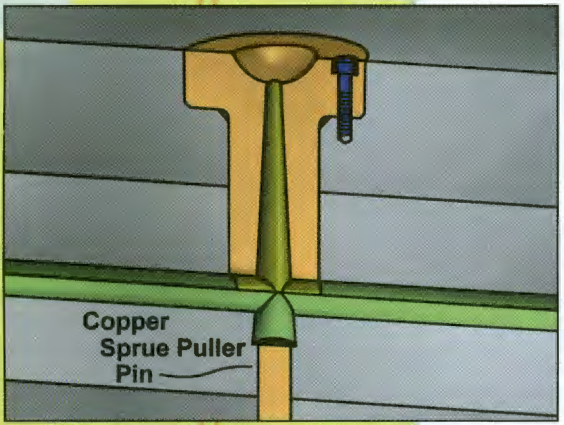

Illustration E: Copper alloy sprue puller pin used to firm up puller and reduce molding cycles.

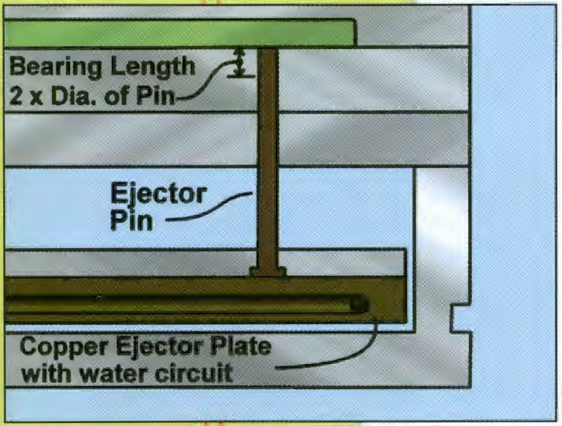

Illustration F: Bearing length of ejector pins is crucial to mold life.

vidually positioned and loaded into its proper location. The components, once committed to a location, should be properly identified and always returned to that position.

Guided Ejector System

Every mold that utilizes small diameter ejector pins or is heavy enough to cause the pins to flex should be equipped with a four post-guided ejector system. The most efficient systems utilize hard surface grooveless leader pins and C95400 or C95900 aluminum bronze bushings. The guides should be located on the four corners of the ejector system to provide the most accurate alignment of the components to the mold core. The objective is to remove any load from the ejector components. Debates range if the leader pins should be installed in the ejector housing or through the support plate. We prefer installing the guide pins in the support plate as this allows the ejector retainer plate to be held in position when the ejector components are loaded.

In those instances when the support plate will be subjected to greater thermal expansion than the ejector plate, additional clearances can be accommodated in the fit of the bushings to the ejector and ejector retainer plate. Placement of the guide pins in the ejector housing removes the element of thermal expansion from the equation, but makes it more difficult to assemble the mold.

Ejector System Return

Every mold should have ejector return pins to insure that the ejector system has positively returned for the start of the next cycle. The most common method is using the standard four return system found on every standard mold base. This positive method of ejector plate return, with the pin head resting on the ejector plate and the tip located at the parting line, only ensures full return when the mold is closed. Frequently, it is desired to either take the load off the return pins or assist in the return of the ejector system. Connecting the ejector system to the machine's hydraulic knock out plates with an ejector rod is common. When the machine ejector system returns, the ejector plate and ejector system also returns.

Many molds incorporate compression springs to aid in the return of the ejector system. Four springs, often located around the return pins, are used. Care must be taken not to over compress the springs and cause premature failure. This method is not entirely fool proof. The ejector system is not positively returned after each cycle and should never be used as the only means of return if damage will result should an ejector component not be returned prior to mold closing. Ejector return springs should be replaced in sets, never individually, to ensure that even pressure is supplied against the ejector plate.

When the ejector system must be absolutely and positively returned prior to the mold closing, early ejector system mechanisms are used. Small molds sometimes use internally mounted early ejector return systems. Medium and large molds use externally mounted toggle mechanisms to ensure that the ejector plates have been positively returned so they will not prevent the mold from closing.

We believe that having a limit switch or electrical signal to ensure the positive return of the ejector system is an important safety consideration. Using a switch alone, without the assistance of an early return system, can be dangerous and result in mold damage should a system electrical failure or false signal occur. ■

Acknowledgements

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Injection Mold Design Guidelines

SIXTH IN A SERIES

Maximizing Performance Using Copper Alloys

By Dr. Paul Engelmann
and Bob Dealey
for the Mold Marketing
Task Group of the Copper
Development Association

Cooling With Copper Alloys

Typically the C17200, C17510 and C18000 copper alloys are used in plastic forming areas of molds because of their high thermal conductivity and unique abilities to attain a more even molding surface temperature.

The key to obtaining and maintaining plastic part dimensional stability and repeatability, critical in three and six sigma molding, is to expose each and every cavity and molding cycle to exactly the same conditions. The molding machine and/or process controls provide the ability to control melt temperatures, screw recovery, injection rates and pressures, cycle time and other parameters associated with the process. Control of both the mold surface temperature and then the range of these temperatures is a separate and frequently overlooked process.

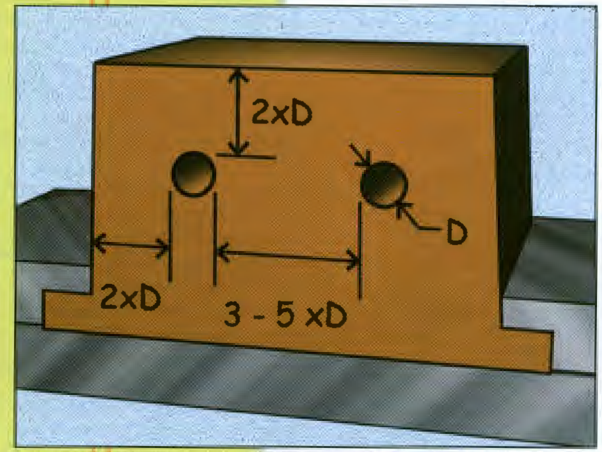

Illustration A: Water channel placement showing position between channel and edge of cavity forming alloy.

After cavity filling, mold temperature control is the single most important factor influencing dimensional control of the molded part. All thermoplastics have to be cooled from their melt temperature to a temperature where they can be ejected correctly without harming the part. Normally we think of the process as just cooling of the mold, but sometimes the mold is heated. Our ultimate objective is to control mold temperature within a range that yields a product within specifications at acceptable cycle times.

Placement of Coolant Channels

Ideal placement of water channels in copper alloys will enhance an already good mold temperature control material. Good design practice calls for the edge of the channels to be placed two times the diameter of the channel away from the molds plastic forming surfaces, see Illustration A. This distance has proven to be effective in providing enough support to prevent deformation of the molding surface and ideal for providing an even mold surface temperature. Closer placement to the plastic forming surface could result in greater temperature variation across the mold surface by overcooling areas in closer proximity.

The pitch, distance between coolant channels, is also an important design consideration. The recommended distance between these channels is two to five times the diameter of the coolant channel. These recommendations have proven effective in mold applications using copper alloys. Frequently, in similar situations with molds built from tool steels, the recommendations are to place the coolant channels closer to the surface with reduced pitch distances. The superior thermal conductivity of the copper alloys allows greater freedom in channel placement.

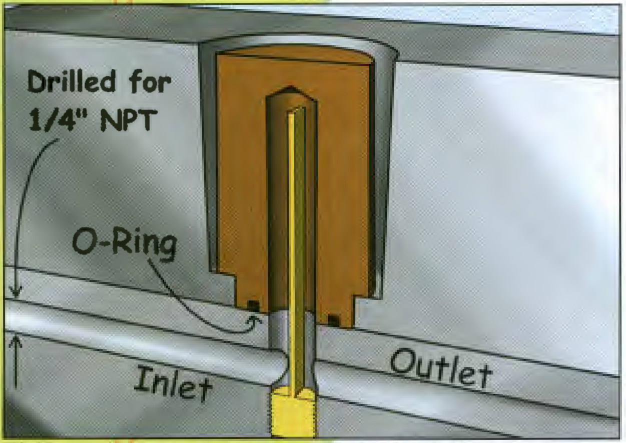

Illustration B: Baffle in series coolant circuit, positioned to force flow up and over baffle and not around.

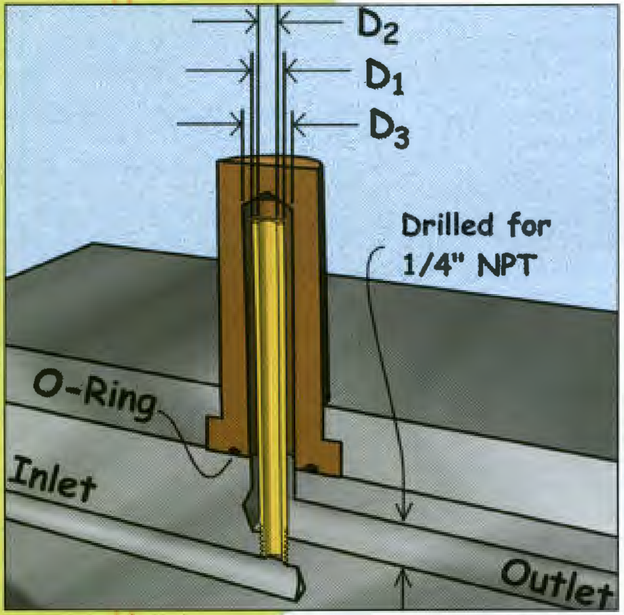

Illustration C: Bubbler in parallel coolant circuit. Area of center of tube should equal area of return.

A fluid circulating pump with capability of achieving turbulent flow rates is an important part of the equation. When using cold mold temperatures, typically below 50 degrees F, closed systems with mixtures of water and ethylene glycol are typically used. These systems require higher horsepower motors to achieve the same flow rates as water as the viscosity of the fluid changes. Temperature ranges between 50 and 210 degrees F usually use plain water. Processes over the boiling point of water generally rely on oil and usually the mold is being heated, even though the mold has to cool the plastic to eject it.

Reynolds Numbers
A method used in mold design to describe the mold temperature control fluid flow in a mold, either laminar or turbulent, is by a dimensionless number. The Reynolds number takes into account the pressure, volume and viscosity of the coolant, the resistance to flow, length and diameter of the channels and the pressure loss in the circuit. Laminar flow in a plastic mold, described by Reynolds numbers below 2,000, indicates conditions whereby heat is not efficiently transferred from the channel wall to the circulating media. Turbulent flow, Reynolds numbers above 5,000, describe conditions where efficient transfer of heat is made from the coolant channel wall to the circulating media. Heat transfer during turbulent conditions can be as much as three to five times greater than with laminar flow. Numbers falling between 2,000 and 3,500 describe a transition phase and typically is ineffective in closely controlling mold surface temperatures.

A simplified formula for determining the Reynolds number for systems using water appears in Injection Molding Handbook, edited by Dominick V. Rosato and Donald V. Rosato. It takes into account the fluid velocity in feet per second times the diameter of the coolant passage times a constant of 7740 divided the viscosity of water. Water viscosity changes as temperatures increase. At 32°F the viscosity of water is about 1.8 centistokes, at 100°F it has changed to about 0.7 and at 200°F about 0.3. This explains why, on occasion, increasing coolant temperature reduces part warpage and cycle time. Lessons learned in production molding have shown that with the use of copper alloys higher coolant temperatures can be used, reducing sweating of the mold and supply lines, while producing a better part at lower cycle times.

Normally mold cool programs are used to analyze effectiveness of heat transfer in the mold due to number of variables affecting the calculation. While better cooling is achieved with higher Reynolds numbers, a point of diminishing returns will be reached. When the circulating media has the capability of removing heat faster than the plastic will give it up, which is typically the case with the proper application of copper alloys, energy in cooling or heating and pumping the circulating media is wasted. Correctly designed coolant systems are important factors in obtaining fast and economical cycle time. The higher thermal conductivity of the copper alloys allows more freedom in this design over traditional tool steels.

An effective method of testing existing mold temperature control systems is to remove an exit line and measure the coolant flow through that circuit. The following table lists the flow nominal size (pipe), drilled whole diameter and the minimum water flow required insuring turbulent flow.

Pipe Size	Drilled Channel Diameter	Min. Flow (gal/min)
1/16-NT	.250	.33
1/8-NPT	.3125	.44
1/4-NPT	.4375	.55
3/8-NPT	.562	.75
1/2-NPT	.6875	1.3

Chill Plates

Earlier injection mold design guidelines describe the effective use of a chill (temperature control) plate made from the same copper alloy to insure the same thermal conductivity. Testing at Western Michigan University has proven the effectiveness of cooling multiple small cores that have small diameters preventing water passages. It is necessary that the core pin heads be firmly seated against a clean and oxidation free plate surface to insure efficient transfer of heat.

Temperature Control Channels with Baffles

Channels that divert temperature control fluids from one level to areas where heat is concentrated in the mold can use baffles, Illustration B, to positively direct the flow through the channel. This type of coolant direction is referred to as series flow when multiple baffles are used. Proper mold design starts with the diameter and area of the inlet channel. The hole for the baffle, after taking the area occupied by the baffle into account, must be twice the area of the inlet channel, to prevent flow restrictions and high-pressure losses. Remember when calculating flow channels that twice the area is not the same as twice the diameter.

Brass baffle and pressure plugs, which resists the build up of water deposits, work best in copper alloys. Most standard off the shelf baffles use a dry seal design, where standard pipe taper is 3/4 inch/foot, the dry seal design features 7/8 inch/foot taper. To prevent high hoop stresses on the copper alloys straight thread pressure plugs must be used instead of either tapered or dry seal pressure plugs.

Another important consideration is the clearance area between the tip of the baffle and the drilled hole. General design practice is to allow the same gap as the diameter of the baffle hole. Make sure that the baffle is installed at a 90° angle to the flow of the coolant to positively force the flow up and over the baffle. Otherwise leakage around the baffle will result in inefficient cooling. An effective method is to braze the baffle blade to the pressure plug and mark the outside of the plug with a line indicating the blade orientation. Check to insure that the blade is properly positioned when the pressure plug is tight.

As temperature control fluid flow is positively directed through each channel, care must be taken to insure that the outlet temperature does not exceed the inlet temperatures by more than 3°to 5°F. High temperature differentials between individual cavities or their mold sections results in undesirable part consistency. Therefore, series circuits typically have a maximum of six to eight baffles.

Spiral baffles are useful in long slender cores as the coolant flows around the baffle, exposing the diameter of the coolant channel to more even temperatures than what could result from having up one side and down the other side of a core. Incorrect assumptions have been made that spiral baffles create turbulent flow, the fact is that spiraling water does not create turbulent flow or result in higher Reynolds numbers, by the fact that the coolant is turning.

Temperature Control Channels with Bubblers

Bubblers are also used to step coolant into areas of the mold that require heat removal. The major difference between the bubbler and the baffle is that water flows up a tube in the center of the coolant channel and cascades down the outside to the outlet, Illustration C. These cooling circuits, when more than one bubbler is used are called parallel circuits. The inlet has to have greater volume than the sum of the bubbler internal diameters to insure that each circuit will have the same flow rates.

Design of the coolant channel and the bubbler is important to successful mold temperature control. The area of the internal diameter of the bubbler tube, D2 must be exactly the same as D3 to insure that high-pressure losses are not encountered. Critical to the calculation is determining the bubbler wall thickness, D1 and the area it occupies. The coolant inlet must feed the bottom of the bubbler tube. The outlet for the coolant is around the outside diameter of the bubbler tube. Each mold coolant channel inlet and outlet must be clearly marked to insure that outside connections are correctly made, insuring the proper flow. Excessive looping can result in high-pressure losses with these circuits and must be avoided to achieve optimum mold cooling.

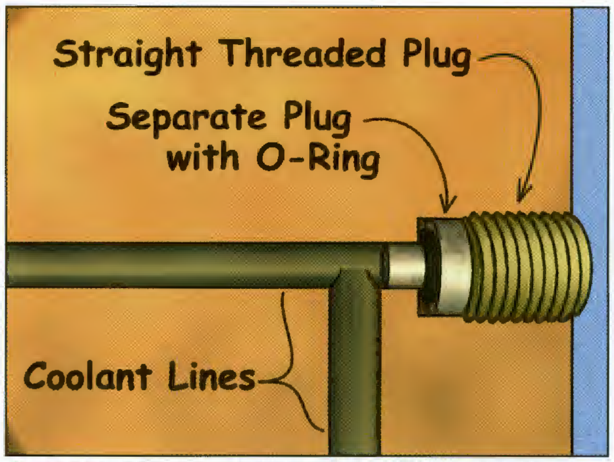

Illustration D: Recommended straight threaded pressure plug and seal.

Drilling and Plugging Coolant Channels

Long coolant channels are typically gun drilled in mold plates, cavities and cores. Typically, even with accurate gun drilling, the hole can wander and the tolerance of hole location is normally understood to be .0.001 per inch of length. Smaller diameter drills tend to wander more than larger diameters. Care must be taken when coolant lines pass close to holes in the mold and adequate clearances must be allowed to prevent break though or leaving a weak section of the mold. With copper alloys the minimum recommended distance is approximately .100", depending upon coolant diameter, distance from drill start and the size and location of the cross hole. Coolant channels should not run parallel or in close proximity with sharp cavity corners to guard against premature failure.

The coolant channels, Illustration D, should be blocked with a fabricated straight threaded brass plug to avoid excessive hoop stresses on the copper alloys. An effective method in leak prevention is to counter bore the plug hole and then use an O-ring installed in compression. The O-ring should be replaced each time the plug is removed or at major mold maintenance cycles. Cross-drilled connecting channels should have the drill point run out in the connecting channel, avoiding stress risers.

Series and Parallel Channels

Coolant channel placement has to be considered and engineered into the mold design from the onset. Efficient mold temperature control

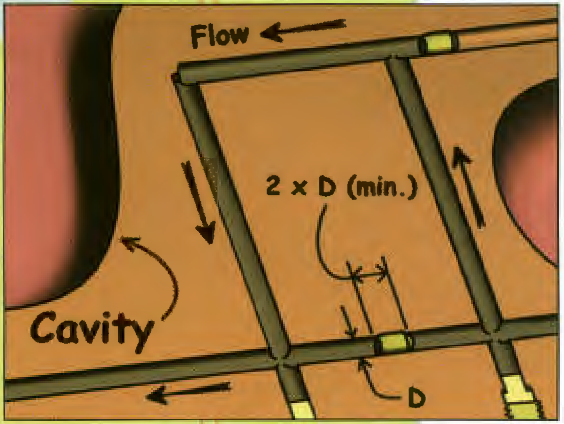

Illustration E: Looped water circuit with diverter.

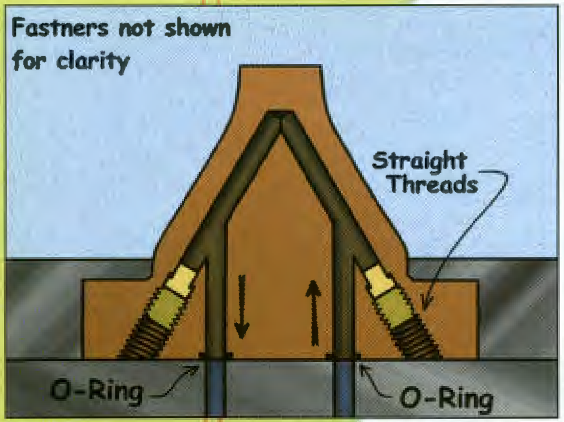

Illustration F: Intersection drilled coolant channels in hard to reach locations.

has to have the same priority in a mold design as gating and part ejection; it cannot be an afterthought. Coolant circuits can loop inside the mold with connecting channels or outside the mold with external connections.

When the mold design calls for series internal looping, and the coolant could flow in more than one direction, flow must be positively routed in the desired channel. A number of diverter plugs are commercially available to block the unused channels and direct flow though the designated route. However, a simple and recommended method is to machine a brass plug .003/.005 smaller than the coolant channel with the plug length twice the diameter, Illustration E. The plug should be inserted into the channel with a light press fit to insure it remains firmly in the correct position. The location should be measured by inserting a rod into the coolant channel and the entire circuit water tested to insure that proper routing without restriction has been achieved.

O-Rings for Sealing Coolant Channels

O-rings, when placed in compression, have proven to be the most effective method of providing a seal between two joining components in a mold. They are placed between mating components when baffles or bubblers are used. Additionally, O-rings are placed between cavity and core components when coolant is directed through the "A", "B" and support plates. The O-ring material type must have a compatible temperature rating within the range of the coolant and mold operation temperature. On occasion a reaction can occur between copper alloys, in the presence of water and/or other fluids and certain mold steels where corrosion or pitting could take place. To prevent the possibility of this electrolytic action taking place, the copper alloy can be chromium or nickel-plated in the O-ring area. The objective is to prevent direct contact between the two materials by using a third compatible material. If the copper alloy component will have a coating or plating applied to the molding surface anyway, covering the whole component will normally suffice. A separate or different coating for the O-ring area should not be necessary.

All Water Lines are Not Straight Through Mold Components

The design and routing of coolant channels can be challenging, especially in mold cores. Straight through drilled passages are not always possible due to mold configuration, mounting and ejector pin holes and other obstacles.
Machining or drilling channels that intersect and direct coolant flow to the desired location, Illustration F, should be considered. The use of innovative design methods, including baffles and bubblers, to insure proper mold temperature control is achieved pays handsome rewards in obtaining an efficient running mold. Coupling these design principles with the use of copper alloys and their superior thermal conductivity provides the best opportunity in achieving optimum molding conditions ■

Acknowledgements

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Injection Mold Design
Guidelines

SEVENTH IN A SERIES

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

Maximizing Performance Using Copper Alloys

Leader Pins and Bushings (Aluminum Bronze Copper Alloys)
Leader pins and bushings provide the initial alignment of the cavity and core halves on mold closing. It is mandatory that the leader pins and bushings engage prior to any mold component entering or making contact with the opposite mold side. Four pins and bushings are used per mold, located at the four corners of the mold base. Sufficient mold base material must remain after machining the bore to provide support for the bushing.

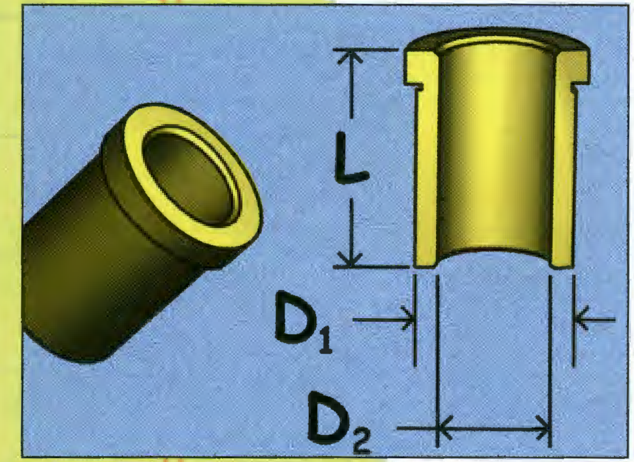

Illustration A: Aluminum bronze leader pin bushing with flange.

Three of the leader pins and bushings are located the same dimension from the edges of the mold base. The fourth bushing is offset at the zero-zero corner, the corner of the mold, which will be the top right hand stationary side of the mold when viewed from the parting line. The offset, insuring that the mold can not be assembled incorrectly, is at least one-sixteenth of an inch. Offset's on larger mold bases, or when space allows, is frequently one-eighth of an inch.

The most effective and longest lasting combination, compared to steel bushings, mates a case hardened groveless leader pin with C 62400 or C 95400 aluminum bronze leader pin bushings. Overall leader pin length should be at least the sum of the thickness of the "A" and "B" plate. The bearing length of the bushing should be two to two and one-half times the nominal diameter of the leader pin.(See Illustration A) Insufficient or excessive bearing lengths will result in premature failure. Maintain pin contact with the bushing at the parting line entrance; install the clearance at the back end of the bushing if necessary.

The normal standard "A" series mold construction, has the leader pins installed in the "A" plate and the bushings installed in the "B" plate. Reversed pin and bushing placement is permissible when warranted due to intentional plate movement. Installing bushings in floating plates and using the four leader pin bushings to guide the plates is standard practice in injection mold design.

Leader bushing length should be the plate thickness in which it will be inserted minus .005 to .010 inches. The counter bore for the flange should be installed .015 inches larger than the bushing to insure that it is not making contact. The plate hole diameter should be machined nominal to .0005 inches oversize to provide for a line-to-line or .0005 interference fit. While a leader pin bushing can be installed in a hole with a greater interference, too tight of a fit will cause the internal diameter of the leader pin to collapse, reducing the desired clearance between the pin and bushing.

The diameter of the leader pin must be sufficiently large to sup-

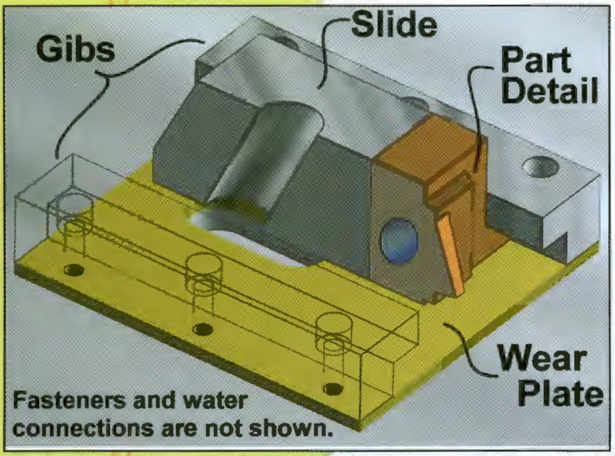

Illustration B: Wear plate installed under slide or moving mold member.

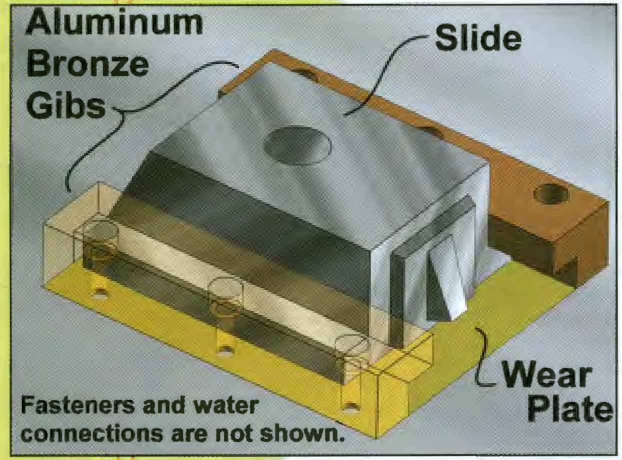

Illustration C: Gibs made from aluminum bronze guide slides and moving mold members.

port the total weight of the mold while, unfortunately, helping to line up the molding machine platens. Table A can be used as a guide in selecting leader pin nominal sizes.

Sizes above those normally considered standard use diameters appropriate for the weight of the mold.

Aluminum Bronze Slide Wear Plates

Mold movements, those not in the normal line of draw, use moving mechanisms referred to as slides, lifters, wedges, cams or side actions. These movements operate better when riding on an inserted bearing surface material. Typical mold base materials make horrible wear surfaces. In the early days of mold building a very hard steel plate was inserted in the mold base to act as a wear surface interface. While effective in providing the hardness differential between the mold base and moving mold component, the mechanism frequently costing $1,000 to $10,000 receives all the damage. The wear plate, with a typical cost of around $100, should be used both as the bearing area and the sacrificial mold component.

Aluminum bronze wear plates, Illustration B, should be used to act as the bearing surface between mold bases, cavities and cores and the moving components. When using aluminum bronze underneath slides the wear plates should extend beyond the bearing area and be retained outside the bearing area. The wear plate should be designed symmetrical if possible (bolt or dowel holes, cam pin clearance slots, etc.), allowing the plate to be inverted should chips or other debris ever mar the surface.

Aluminum Bronze Slide Gibs

Guides, either "L" or "T" shaped are used to locate and retain moving mold members. The most common application is with slides. Illustration C shows aluminum bronze gibs guiding of a convention slide movement. The mold should be designed for the slide gibs to guide the moving slide member for the full travel. Depending upon the weight of the slide carrier and the size of the mold the slide gibs should be long enough to provide accurate alignment of the slide to the mold cavity or core. The gib must act as a guide over the entire length of travel. They should be doweled using two solid dowels, with a clearance hole through the wear plate, to the mold base or mold component. It then should be held in place with two or more cap screws with the heads recessed into the gib.

The gib will serve two functions. The first is to precisely guide the slide in its movement and mating with the mold cavity and core. To accomplish this "Running or Sliding Fits" (RC class) is typically used in the mold design. Depending on the accuracy of alignment the standard tolerance range using American National Standard Institute tables falls between a

Recommended nominal leader pin and bushing diameter by mold base size											
Width	Mold base lengths (up to)										
	8	9	10	12	14	16	18	24	26	30	36
7 7/8	.75	.75	.75	.75							
9 7/8	.75	.75	.75	1.00	1.00	1.00	1.00				
10 7/8				1.00	1.00	1.00	1.00	1.00			
11 7/8				1.00	1.00	1.00	1.00	1.00			
13 3/8					1.00	1.00	1.00	1.00	1.00	1.00	
14 7/8						1.25	1.25	1.25	1.25	1.25	1.25
15 7/8						1.25	1.25	1.25	1.25	1.25	1.25
16 1/2						1.25	1.25	1.25	1.25	1.25	1.25
17 7/8							1.25	1.25	1.25	1.25	1.25
19 1/2							1.25	1.25	1.25	1.25	1.25
23 3/4								1.50	1.50	1.50	1.50
25 7/8									1.50	1.50	1.50
To 36											2.00

Table A: Nominal diameter of bushings by mold size.

H5 and a H8 for the dimension between the gibs and a g 4 to an f 7 for the slide carrier. As always, when providing clearances in injection molds the overriding factor is to insure against flash while holding the required product dimension. When those two considerations have been accounted for, only then can the application of normal clearances be incorporated to the mold to achieve the desired condition.

The second function is for the gib to retain the slide and keep it from derailing. Clearance up and down can be greater than side to side if the opposite mold side will hold the slide in position in molding. If no contact will be made when the mold is closed, than the slide gibs must provide that assistance.

Gibs have two surfaces that could be used to assist in guiding the slide carrier. Only one surface should be used as the bearing guide, typically the top surface. The other surface should be cleared an additional .001 of an inch or more to reduce friction.

Aluminum bronze Guided Ejector System Bushings
High-speed molds using small diameter ejector pins require support for the ejector and ejector retainer plate to insure smooth operation. Another effective use of aluminum bronze is in the bushings used in conjunction with groveless leader pins installed on the ejector side of the mold. Leader pins, with nominal diameters of .750, 1.00, 1.25, 1.50 and 2.00 inches, are placed at the four corners in the ejector housing. The greater the mold length and the heavier the mold plates, the larger the nominal diameter of the leader pin should be. (Illustration D).

Common practice is to insert the leader pin head into the support plate. This provides a safe, handy and convenient method for the mold maker to assemble the ejector system as the ejector plates are supported in the proper position. The only disadvantage to this construction method is if the support plate will have a higher rate of thermal expansion that the ejector plates. When high mold temperate differentials are anticipated, mounting the leader pin heads in the ejector housing plate reduces interference created by uneven thermal expansion between the two components.

When manufacturing guided ejector bushings, the shoulder is placed closer to the middle of the bushing. A counter bore is machined in the ejector plate to trap the bushing between it and the ejector retainer plate. The bushing should be designed to extend the full thickness of both the ejector and ejector retainer plates. The side wall of the bushing should be one-fourth of an inch to provide strength. As the guided ejector system is difficult to access in the assembled mold, a method to lubricate from the outside of the mold is recommend. Grease fittings into connecting spiral grooves machined into the bushing is the preferred method of providing lubrication to the bearing surfaces.

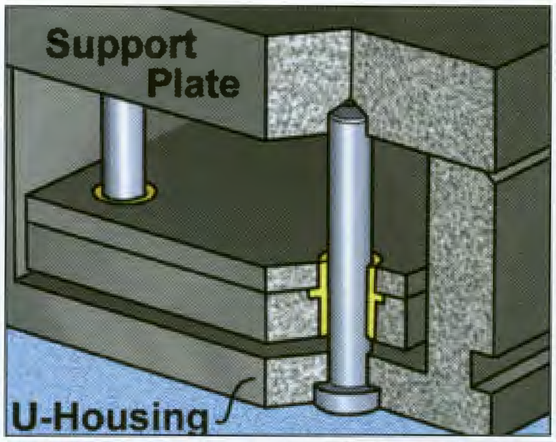

Illustration D: Four aluminum bronze bushings with mid-busing flange used to guide ejector system.

Angle Interlock Face Plates
Injection mold leader pins and bushings act as a rough alignment system. Interlocks are used to provide the final and precision mating of the cavity and core. Two styles of interlocks are used. The first is straight interlock and its function is to line up the two mold halves prior to the mold closing. These interlocks are either mounted on the side of the mold base and are called straight side locks or mounted on the face of the mold at the parting line and called top mount interlocks. Straight interlocks normally align the entire mold rather than individual cavities and cores and the interlocking concept and is used when alignment is necessary on mold closing. This system is mandatory when using vertical shut offs or telescoping cores.

The second style of interlocking is a tapered concept installed in the mold base or on the cavity and core. This interlocking method is used when the objective is to hold the two mold halves in register during the mold filling and cooling stage, obviously after the mold has closed. This type of interlocking insures that the mold halfs, when closed will not shift in relationship to each other. The nominal angle for this interlocking system is typically not less than 10 or more than 15 degrees. The female interlock is almost always on the cavity side of the mold. Placing the female interlock on the side of the mold that runs the warmest reduces the incidence of the mold not closing due to differential of thermal expansion created by the normal practice of running the cavity side of the mold warmer. Larger molds use a double tapered interlock system where the interlocks are machined directly into the mold base, or in mono-block construction, the cavity and core blocks.

Aluminum bronze wear plates, Illustration E, mounted on the face of one of the interlock serve three extremely important functions. First, they prevent galling, common when two similar steel interfaces would normally contact each other, due to the differential in hardness and material composition while providing low friction characteristics. Next, the aluminum bronze faceplates provide an efficient method of fitting and adjusting during mold construction or at mold maintenance intervals. Last, they are less expensive to replace should any damage to the interlocking system occur over the life of the mold. Aluminum bronze faceplates should be at least one quarter of an inch thick and mounted with recessed flat head screws.

Friction Between Materials
Friction has been described as the resistance to motion when one component is moved upon another. It typically is defined as "that force which acts between two bodies at their surface of contact, so as to resist their sliding on each other." Every moving part in a mold must overcome friction to perform its function with the least amount of force. Therefore low coefficients of friction are a desirable attribute. The measurement used is based on the coefficient of static friction. These values will be higher than those describing sliding friction. Two categories of fric-

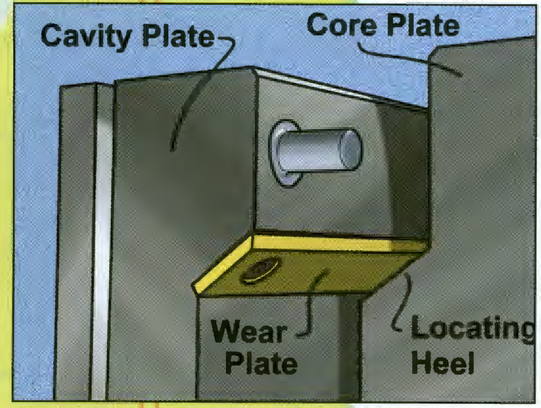

Illustration E: Wear plates used on mold interlocks.

tion should be viewed. The first when the components do not have lubrication and the second, when lubrication is used. Table B lists static coefficient of the two materials. In additionally using dissimilar materials will prevent galling and transfer of the material from one component to the other. The use of aluminum bronze will provide a superb bearing surface and will be inexpensive to install and maintain. All moving parts in an injection mold, with the exception of ejector pins and ejector sleeve and components making direct contact with the plastic material should use lubrication. Typically a high temperature lubrication that will not migrate is recommended.

High Wear Areas in Molds

Although the copper alloys C 17200, C17510 and C 18000 are generally recommended for cores in plastic forming areas of the mold, there can be applications where C 62400 or C 95400 is a viable option. One such application is when lifters are used to mold slight undercuts and the mechanism is mounted on the side face of the core. The thermal conductivity rate of the material is better than that of steel, but not as good as the plastics forming alloys. The aluminum bronze, with its great non lubricated wear properties and low coefficient of friction, has been shown to be the ideal material for these applications. Caution should be used not to install delicate detail close to side walls, as the material does not have the strength of the C 17200, C 17510 or C 18000 alloys.

Static coefficients of friction when steel is in contact with steel or aluminum bronze

Material	Not Lubricated	Lubricated
Steel against steel	0.8	0.16
Aluminum bronze against steel	0.35	Not measurable

Table B: Static coefficient of friction between mold materials.

The mounting, sliding and pivoting ends of lifters is another great application for the aluminum bronze materials. Wear plates and guides for wedges and raising mold members all benefit from the ideal bearing surfaces provided by the C 62400 or C95400 materials.

In addition to leader pin and guided ejector system bushings, aluminum bronze bearings are used to provide a wear surface for large diameter ejector return pins and to support knock out rods extending through the ejector housing. The material serves as an excellent guide method on racks used in unscrewing molds and moving cams in molds.

Experience has shown that the C 62400 or C 95400 aluminum bronze copper alloy is an effective method of providing an excellent round or flat bearing surface in injection molds and plastic tooling. The life of a mold is greatly extended with the application of this material and the cost of maintenance is reduced when the lowest cost component requires replacement. ■

Acknowledgements

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Injection Mold Design Guidelines

EIGHTH IN A SERIES

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

Maximizing Performance Using Copper Alloys

Protecting Copper Alloys With Plating

Frequently various coatings or platings are used in injection molds to prevent corrosion or erosion from the plastics attacking the mold. Coatings can reduce mold maintenance intervals while extend mold life. Copper alloys, C17200, C17510 and C18000 utilized for their high thermal conductivity properties to improve part quality and reduce cycle times, are no different than tool steels when protection is desired.

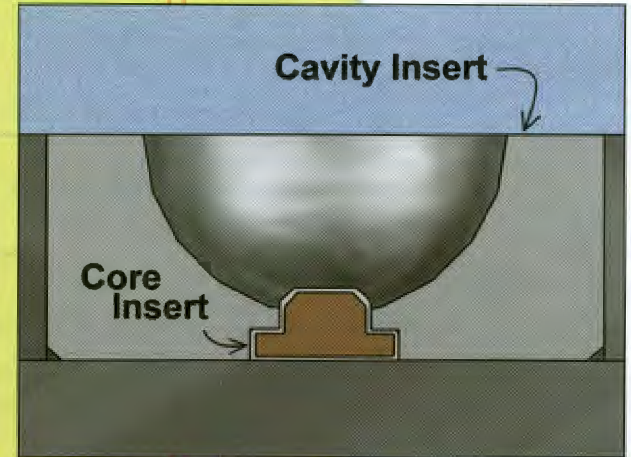


Illustration A: Use of copper alloy in cavity for thermal conductivity and plated to isolate it from the steel cavity.

Copper alloys in the presence of some plastic residues will react with mating steel components and create an electric current flow, similar to a battery. Isolating the copper- to-steel contact, Illustration A, with plating eliminates the galvanic action between the two materials and prevents the formation of small amounts of tarnish that could transfer to the plastic part. Typically the insert is completely covered with the plating.

Preparing Surfaces for Plating

The desired SPI surface finish, A-1 through D-3, should be applied to the copper alloy prior to shipment to the plating source. The plating will generally duplicate the surface where it is applied. A very rough surface finish will improve slightly when plated and a smooth highly polished surface will appear less polished. The plating process will not cover scratches, nicks and surface imperfections. Any mold defects must be removed prior to plating.

While it is a common and acceptable practice to sample a mold prior to plating, it is necessary to remove all traces of plastic from the component and notify the plater that the mold is used. Mold drawings, indicating the molding surfaces to be plated, should accompany the components to the plater. Masking surfaces where the plating is not desired can and should be noted on the mold drawings, if there is a good reason for not applying plating. However, masking can be a time consuming and expensive operation and it is normally a better choice to plate the entire component when it will not interfere with the molding process.

Choices for Protecting Copper Alloys

A wide variety of platings and coatings are available to protect your mold components. Some are more effective than others and individual choices will vary depending upon the application and experiences with your type of applications. Additionally, the quality of a given plating or coating may be very dependant upon the company that did the work.

Based on studies taking place at Western Michigan University two types of platings are showing the most promise depending upon

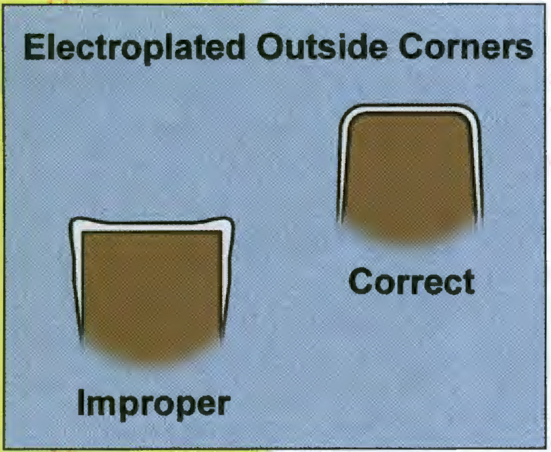


Illustration B: Outside corners illustrating build up on outside sharp corners along with the correct application of radii.

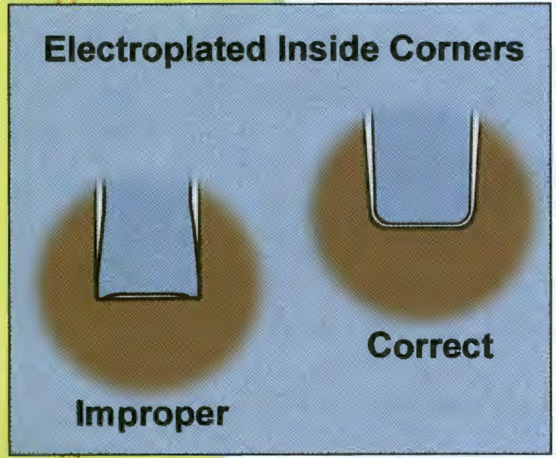


Illustration C: Sharp inside corners on channels without draft results in uneven plating. Draft on the walls and radii on the inside corners allow for an even build up of chrome.

the specific application, chrome electroplating and electroless nickel. The first and most effective protection against wear caused by impingement of glass filled nylon against cores is a variety of electroplated chrome platings. These chrome platings fall into one of four categories; standard industrial hard chrome, industrial hard chrome with its structure filled with a polymer, densified chrome platings and chrome composites like Armoloy's XADC a nodular chromium containing nanocomposite of diamond.

Chrome Electroplating
The electroplating process uses electrical current to deposit the chrome on the mold component surface. Both ferrous and nonferrous materials conduct current around the outside of the component and as a result the process attracts more chrome to outside sharp corners than flat surfaces. However, the copper alloys are such great electrical conductors that corner build up is accentuated over comparable steel components. See Illustration B. To reduce the build up, sometimes referred to as chrome trees or dog bones, the use of generous outside radius is recommended on the components outside corners. Obviously, the plastic part and its function must be able to accept the radius without detrement. Normally a generous radius, outside edge on the mold component and inside edge of the plastic part, adds great strength to the part and is typically a great benefit.

This electroplating process also creates problems on sharp inside corners of the mold component, see Illustration C. A sharp corner, due to current flow, will be starved of chrome. A generous radius on the inside corners allows for a more even build up and will prevent chipping at the corners.
Channels cut into mold components (for forming ribs on the plastic part) create problems in electroplating. When the depth is greater than one half the width, plating thickness will vary considerably and diminish on the sides of the walls as the depth increases. Illustration D shows a typical condition encountered in molds. The sharp outside and inside corners, coupled with the depth of the channels prevents the chrome from building up evenly. Illustration E exhibits a more ideal construction method using an insert eliminating the channel depth-to-width problem. Additionally, the generous outside radius eliminates the problem of excessive outside corner build up, while the inside radius reduces corner starvation. When mold components can not be modified to optimize the electroplating process then anodes have to be built to get the plating down into deep channels.

Benching of Electroplated Mold Components
Mold components must be benched after electroplating. Any overhanging chrome deposits must be removed prior to sampling the mold or the plastic will form around the build up and the results will either be sticking of the plastic part or the chrome tree breaking off or chipping exposing the parent material. Illustration F shows chipping of chrome in a gate area. Two methods are normally used to remove the chrome build up. The first is with a hard 600 grit stone and carefully stoning the surface in the direction of draw, removing any chrome build up which would create an undercut.

The second method, performed by a skilled mold maker, uses a nylon brush mounted in a rotary tool operating at a slow speed with light pressure and a chrome polish. The surface is gently worked, carefully removing only the overhand so as not to destroy the intended plating thickness or reducing adhesion to the mold component. Caution has to be used, as to much pressure and/or high removal rates can cause chipping and exposure of the parent material.

Electroless Nickel
The second category of protection is electroless nickel

applied by an auto catalytic (without current) process. The advantage of electroless nickel is that the surface is covered to a uniform thickness compared to most of the electroplating processes. As the deposition is applied uniformly and without current due to the electroless process, special draft angles are not necessary and the process is forgiving on both inside and outside corners. The disadvantage is that the hardness of nickel is in the 50 Rc range, a lower hardness than many of the other platings available. Additionally, nickel is not a great bearing material and it should not be used in applications with moving parts.

Plating of Holes

Electroless nickel has the advantage of covering side surfaces of holes or channels with large aspect ratios. Sharp inside corners on blind holes are difficult to cover and a radius is recommended on any blind hole. On holes up to .125 inch in diameter the depth is limited to about .750 inch due to problems associated with getting the gases out of the hole. There is no practical limit to the depth of plating electroless nickel in holes greater than .125 inch on conventional molds. (Table 1)

Electroplating chrome into holes is more difficult than applying nickel. Frequently, anodes have to be built to assist in the application process. The cost of constructing the anode can be a significant additional cost not encountered with electroless nickel. Maintaining the proper position of the anode also adds difficulty in the plating process. Not withstanding the cost and difficulty, one plater uses the information listed in the following table as a guide to maximum depths of chrome plating into blind or through holes.

Deposition Thickness

The best thickness to apply a coating to a mold component is an age-old question and opinions differ widely. Experience and extensive testing at Western Michigan University shows that a thin layer of protection is extremely effective. The first consideration has to be to insure that the plating will adhere to the patent metal. This favors a thin layer over a thick layer. The second consideration is to the reason why the plating was applied in the first place and if a thicker layer will provide better protection.

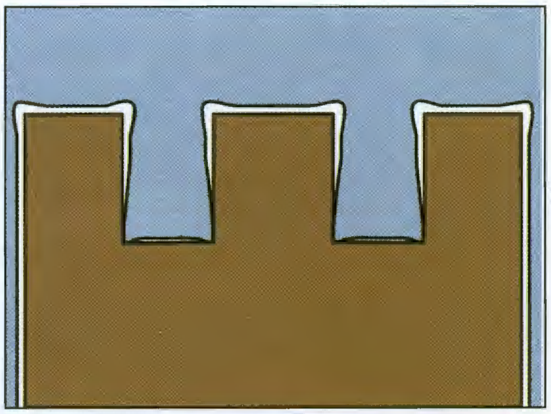


Illustration D: Illustration shows the uneven plating build resulting from typical mold construction practices. Chrome build up is thick on the outside corners and thin to non-existent in the channels.

Table 2 lists plating thickness, which have proven to be effective in protecting copper alloys used in plastic forming applications.

Deposition Temperatures

Care must be taken to avoid exposing all materials used in mold construction to excessive heat which could stress relieve or anneal the component. The copper alloys should not be exposed to temperatures above recommended manufacture specifications, typically around 400 degrees F. The electroless nickel process is typically less than 200 degrees F. Chrome electroplating usually has a process temperature of 185 degrees F or less. PVD or CVD process can run up to and sometimes exceed 400 degrees F. Considerations must to be given to the use of processes that expose copper alloys to temperatures approaching 900 degrees F, such as those found in some titanium nitride processes. Exposing copper alloys and some other mold alloys to high temperatures for extended times can be detrimental to their properties.

Reasons for Plating Mold Components

Copper alloys are plated to extend periods between maintenance or component replacement intervals and to improve part quality. Most plating is applied to protect plastic forming components from erosion and premature failure resulting from running glass or mineral filled plastics. Testing underway at Western Michigan University, using 33% glass filled type 6 nylon in an eight cavity mold, has shown that copper alloy cores protected with some of the chrome processes have extended component life up to 20 times longer when compared to non-plated P-20 cores.

The second reason is to protect against corrosion. The copper alloys are naturally resistant to attack from most plastics. However, to prevent tarnish and the transfer of residue created by the interaction with steel, plating of copper alloys is an effective prac-

TABLE 1. Depth of Electroplating Chrome in Holes

Hole Diameter	Blind Hole		Through Hole	
	Typical Range	Maximum Depth	Typical Range	Maximum Depth
.125	0.00-0.75	1.00	0.00-1.50	2.00
.250	0.00-1.50	2.00	0.00-3.00	4.00
.500	0.00-6.00	8.00	0.00-12.00	16.00
.750	0.00-12.00	18.00	0.00-24.00	36.00
1.00	0.00-24.00	36.00	0.00-48.00	72.00

*All dimensions are in inches

TABLE 2.

Plating Process	Ideal Thickness	Maximum Thickness
Electroless Nickel	.0005-.0007	.001
Flash Chrome	.0001-.0003	.001
Thin Dense Chrome	.000050-.0005	.0005
Thin Dense Chrome with Diamond	.000050-.0005	.0005

*All dimensions are in inches

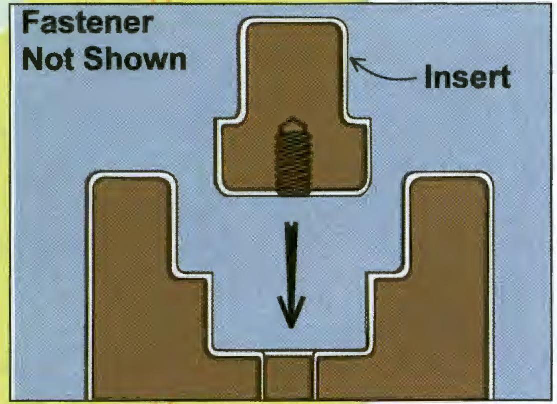


Illustration E: This illustration shows a suggested method of manufacture that results in a component that can be plated to an even thickness.

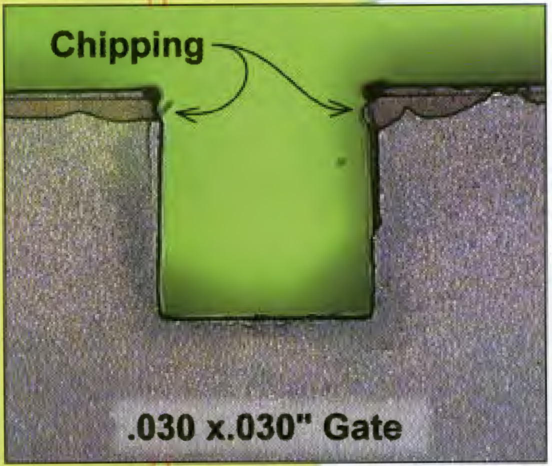


Illustration F: Chipping in gate area caused by improper removal of chrome build up at the corners.

tice. Nickel is recommended over chrome when molding polyvinyl chloride, as hydrochloric acid will strip chrome from the component surface. Chrome works well with most other plastics.

Another reason for applying plating is for wear associated with stripping abrasive plastic parts from cores. As chrome has a higher hardness level, it proves to be more effective than nickel. In mold areas where components are in moving contact, the nodular chromes tend to work best. The sliding coefficient of friction of non-lubricated nodular chrome against nodular chrome is around 0.14. This compares to a rating of 0.20 of steel against steel. Nickel does not hold up as well in rubbing applications.

The last reason for plating is to improve mold release. Nickel and chrome with impregnated polymers are offered by a number of companies as a solution in reducing friction and improving part release. Other companies offer wide ranges of platings and coatings in which they claim success in resolving release problems. Due to the wide range of mold conditions and plastic part design, it is difficult to qualify what process works better. However, if is safe to say that the first priority has to be to allow adequate draft angles and provide proper ejection mechanisms as a first step to insure part release. Next, the mold component must be benched properly. This includes removing all machining marks and stoning or polishing in the direction of draw with the proper grits, prior to applying the desired surface finish.

The plating should only be applied after the plastic forming mold surfaces have the proper finish. A coating or plating will not resolve all release and ejection problems; especially those created by improper mold finishes.

Affect on Thermal Conductivity of Copper Alloys

Extensive laboratory testing on the affect of nickel or chrome plating on thermal conductivity is scheduled by the CDA. At this time the experience gained in running thermal studies indicates that there is no measurable loss in cooling effectiveness when comparing the same plated and non-plated mold cores. Similarrly, no significant change in cycle time, have been reported in situations where molds are sampled without plating and then plated and run in production. One theory is that the high thermal conductivity of the copper alloy overcomes any reduction in heat flow from the plastic part that the thin layer of plating could create.

Allowing for Plating Thickness

In certain situations the thickness of the plating has to be taken into account in mold design. Fits of inserts, for example, should allow for the increase in size due to plating thickness insuring proper mold function. These allowances are typically in the range of tenths to a few thousands of an inch. ■

Acknowledgements

The injection mold design guidelines were written by Dr. Paul Engelmann, Associate Professor, Western Michigan University and Bob Dealey, Dealey's Mold Engineering, with the support of Dr. Dale Peters, for the Mold Marketing Task Group of the Copper Development Association. Kurt Hayden, graduate research assistant, WMU, generated the illustrations. Research conducted by WMU plastic program students.

Disclaimer

These guidelines are a result of research at WMU and industry experience gained with the use of copper alloys in injection molding. While the information contained is deemed reliable, due to the wide variety of plastics materials, mold designs and possible molding applications available, no warranties are expressed or implied in the application of these guidelines.

Contact Information

Information on copper alloys is available from the Copper Development Association, at 800-232-3282. Technical clarification of the guidelines can be made by contacting Bob Dealey, Dealey's Mold Engineering at 262-245-5800

Injection Mold Design Guidelines

This Ninth Design Guideline will address applications of copper alloys in molds

Maximizing Performance Using Copper Alloys

By Dr. Paul Engelmann and Bob Dealey
for the Mold Marketing Task Group of the Copper Development Association

Picture A:

Picture B

Picture C

Injection Mold Core Applications

Copper alloys, specifically C 17200, C 17510 and C 18000 continue to enhance performance, reduce cycle time and cost, and improve part quality in injection molding applications. The injection mold core is responsible for removing the majority of the heat from the injected plastic and mold materials with high thermal conductivity consistently outperform those materials with low thermal conductivity.

Advantages of mold materials with high thermal conductivity include not only reduction of the cooling phase of the molding process, but also contribute to dimensional control with less tolerance deviation, less part warpage, fewer molded-in stresses and reduced incidence of sink marks.

Copper Alloys for Cycle Reduction

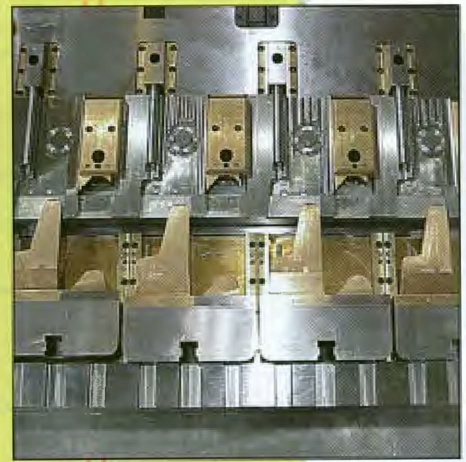
The tremendous thermal conductivity, along with their high density and excellent tensile strength, makes copper alloys an ideal choice for a core material. Molders are reporting between 20 and 50% reductions in the cooling portion of the molding cycle. Kodak, for example in a recent article, reported that in a test mold "copper alloy cores ran 18 deg F cooler than the 420 stainless steel cores." The copper alloys are used in both large and small molds. In large molds, (Picture A), coolant channels are machined into the core similar to ferrous materials. The higher thermal conductivity, up to nine times greater than some tool steels, controls the mold temperature evenly and closer to the temperature of the circulating media.

Smaller mold cavity and cores (Picture B), where installing cooling channels in the proper position is a common problem, benefit from the high thermal conductivity of the copper alloys. When coolant cannot be circulated through the small mold core, channels surrounding the core provide an excellent method of extracting the heat from the plastic part, allowing for faster cycles.

High cavitation, high-speed molds benefit from the rapid heat removal characteristics of the copper alloys. These fast cycling molds frequently running in single digit seconds, benefit greatly from the rapid transfer of heat from the molding surface through small diameter cores. Due to the size of many of these mold components coolant channels are impossible to install in the normally recommended proximity to the molding surfaces. The high thermal conductivity of the copper alloy cores transfer heat effectively while maintaining even mold surface temperatures. Multiple small diameter core pins, (Picture C), in contact with chill plates have proven to be an extremely effective method of cooling cores in studies conducted at Western Michigan University. While results from mold-to-mold will vary, the test mold at WMU using the chill plate cooling method, with no coolant circulating in the cores, runs at less than a six second cycle time. This compares to 15 seconds with tool steel cores and a steel chill plate.

Sink Mark Reduction

Sink marks on injection mold parts, resulting from the delayed solidification in heavy part sections after


Picture D


Picture E


Picture F


Picture G

the gate has frozen off, can be reduced by application of high thermally conductive copper alloys in strategic positions around the heavy sections. In thick wall and boss sections, coring out sections of plastics with copper alloy core has proven to be an effective method of both reducing the incidence of sink marks and cooling times.

Tighter Tolerances

When product designs call for tight dimensional tolerances with quality levels demanding three or six sigma molding, all molding parameters must be closely held. A constant and uniform mold surface temperature will provide for the greatest opportunity to produce parts with the narrowest tolerance range. The copper alloys, with their great thermal properties coupled with good mold temperature control, provide the right combination for tolerance control in injection molds.

Injection Mold Cavities

In situations where plastic shrinks away from cavity surfaces, cooling conditions are less demanding and the copper alloys are used more in applications where "A" side coring is required. Television backs, for example, have large amounts of detail cored from the cavity side. In these molds, cooling cycle time reductions of 25% have been reported by replacing ferrous inserts with copper alloys. Entire sections of cavities have been inserted prior to final machining and the finished cavity detail has been machined in assembly, reducing mold building, benching and finishing costs.

Injection Mold Slides

Coolant channels are typically difficult to install in slides and moving members of molds. These internal mold actions are usually in locations where proper cooling is paramount for the dimensional stability and/or function of the plastic part. With the sophisticated plastic part design levels demanded from today's injections molds, mold surface temperature control is mandatory in the molding process. (Picture D), shows the use of copper alloys in a four-cavity mold, where due to multiple core draws the part interior is formed entirely by slides. The copper alloys are ideal choices for these slides, as most of the heat from the plastic must be transferred through the alloys to the cooling system.

Core, Sprue Puller and Sucker Pins

Standard off the shelf pins made from C 17200, C 17510 or C 18000 (Picture E) have enjoyed huge success in molds with their ability to transfer heat from the contact area to the base of the pin. A sprue puller pin made from copper alloys rapidly set the puller end of sprue and provides an excellent surface area to hold the sprue on the ejector side of the mold.

Material saver core pins utilized to remove plastic and cool designated areas are the most inexpensive applications of copper alloys while perhaps providing the greatest benefit in reducing the mold cycle time. Three plate molds, where the sucker pins must hold the gate drop firmly to allow the gate to break, cycle faster when the plastic under cut area sets up quicker.

Cladding or Bimetal Inserts

When the properties of both ferrous and copper alloys are required for a particular application, swaging of copper alloys around materials like 420 SS have been used (Picture F). The swaging process insures complete thermal contact without the worries of oxidation forming between the two materials.

Blow Molds

Copper alloys, C 17200, C 17510 and C 18000 have superior corrosion resistance in the presence of polyvinyl chloride and is the material of choice for clear blow molded cavities (Picture G). Again the high thermal conductivity rates of the copper alloys, coupled with their high densities, produce the best molding cycles. Another advantage is the high degree of luster possible with the alloys.

In other applications where neck and tail pinch offs are inserted, the copper alloys are normally specified because of their excellent tensile and compressive strengths. These materials continue to prove superior to aluminum in pinch off applications. Additionally, blow molds that require tight dimensional control and long mold life specify copper alloys for their mold material.

Ejector Sleeves

The aluminum bronze materials, C 62400, C 95400, with their excellent wear characteristics and low

Picture H

coefficient of friction make excellent ejector sleeves (Picture H). As the alloys do not require heat treatment after machining, ejector sleeves maintain roundness better than most ferrous alloys. The secret of holding close tolerances on thin walled ejector sleeves is to machine the internal diameter first and then mount the sleeve on a mandrel and complete the outer diameters. With this method, ejector sleeves with wall thickness as low as .040 inch are routinely built.

Lifters

Internal undercuts requiring lifters (Picture I) can prove to be troublesome. These components typically have narrow cross sections prohibiting the installation of coolant channels. As they are in direct contact with large plastic surface areas massive amount of heat must be removed from the lifter. The aluminum bronze materials C 62400 and C 95400 work well in these applications providing that thin wall sections are avoided. While the thermal conductivity is not as good as the copper alloys recommended for mold cores, it is superior to the ferrous alloys.

Wear Plates

Number one through five mold base materials make poor bearing surfaces for ferrous slides and carriers. Inserting the mold base (Picture J) with one-quarter to one-half inch aluminum bronze plates provide one of the best wear combinations available for injection molds. Symmetrically designing the wear plates doubles the life, by allowing it to be inverted should damage occur. Additionally, if a burr or chip gets between the wear plate and slide surfaces the wear plate will suffer the damage, rather than an expensive slide.

Slide Gibs

Guiding slides with "L" gibs built from aluminum bronze (Picture K) has become the standard mold of the mold industry. The gibs with their low coefficient of friction against lubricated steel provide an exceptional bearing surface allowing for a close running fit between it and the slide. This close fit insures proper slide to core and/or cavity alignment and guarantees a precision fit.

Sprue Bushings

When a large diameter sprue is necessary for maximum injection pressure the molding cycle could be controlled by the thick mass of plastic. Sprue bushings (Picture L), built from high thermal conductive copper alloys, remove heat more efficiently setting the sprue quicker. Other applications use the copper alloy sprue bushing to purposely increase the orifice diameter reducing pressure loss in the feed system.

Runner blocks

Long and large diameter runner systems used in fully balanced high cavitation molds typically have huge primary runners. These large diameter runners concentrate large amounts of heat in a small area and the molding cycle must be lengthened to enable runner ejection. The C 17200, C 17510 and C 18000 copper alloys, inserted on both the "A" and "B" mold side with coolant circulating in the runner bars, sets the runner faster while reducing the overall molding cycle.

Leader Pin Bushings

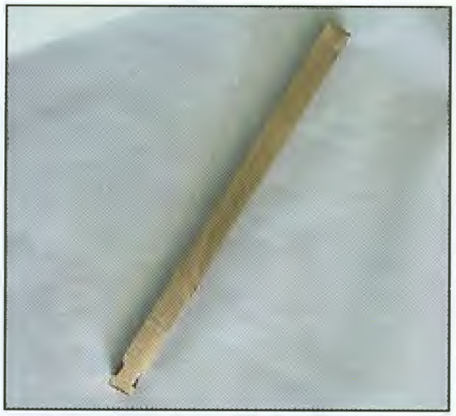
The four leader pin bushings in an injection mold are crucial to initial mold alignment and grooved steel leader pins against steel bushings can rapidly deteriorate. Aluminum bronze leader pin bushings (Picture M) running against groveless leader pins have proven to be one of the most ideal and long life combinations in mold applications.

Guided Ejector Bushings

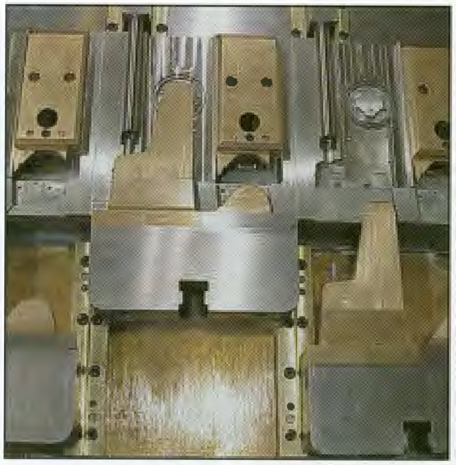
A smooth operating ejector system is mandatory in long running and high-speed injection molds. Utilizing aluminum bronze guided ejector bushings (Picture N) results in minimal wear even in installations where lubrication is hard to apply.

Unscrewing Rack Guide Bearings

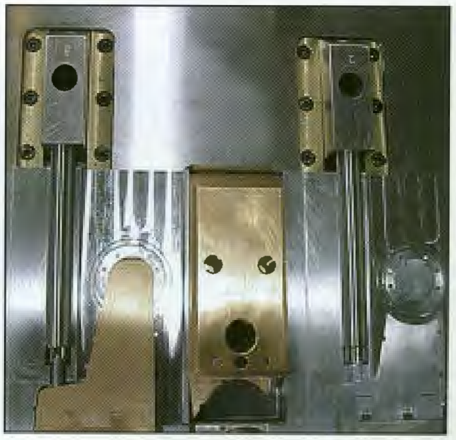
Moving mold components, such as unscrewing racks and cam bars which require high speed and close running fits, benefit by aluminum bronze flat bearings inserted



Picture I



Picture J



Picture K

Picture L

Picture M

Picture N

between the component and mold base. A light coating of high temperature non-migrating lubricant will provide an excellent low friction surface.

Runnerless Molding Systems Components

Runnerless molding systems, frequently referred to as hot runners, probes, drops and bushing divergent tips, benefit from the fast heat transfer provided by copper alloys (Picture O). Materials with high rates of thermal conductivity allow the heat source to be some distance from the tip while maintaining and controlling temperatures within a close range. The importance of maintaining uniform tip temperatures in the gate area on an RMS cannot be emphasized enough. Plating of the probe or bushing will extend component life when molding abrasive materials. ■

Picture O

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