Injection Mold Design Guidelines

Maximizing Performance Using Copper Alloys

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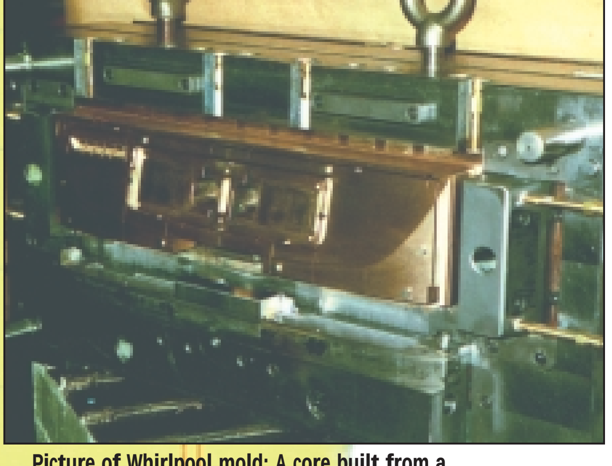
for the Mold Marketing Task Group of the Copper Development Association

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-

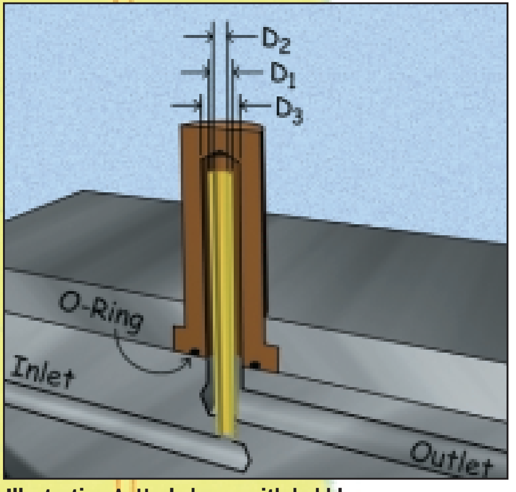


Illustration A: Heeled core with bubbler

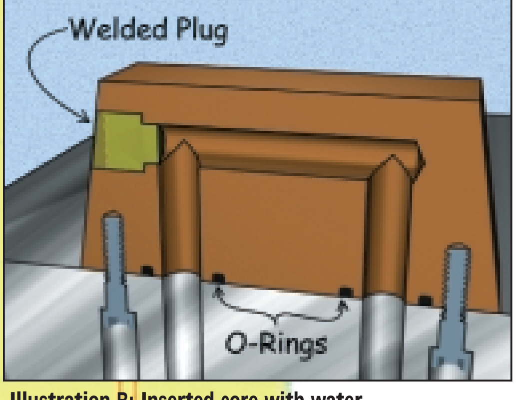


Illustration B: Inserted core with water channels

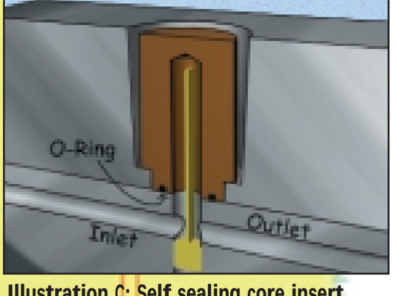


Illustration C: Self sealing core insert

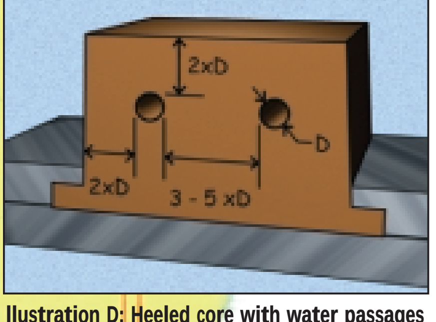


Illustration D: Heeled core with water passages

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:

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

Where: H = Quantity of heat in Btu conducted
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.

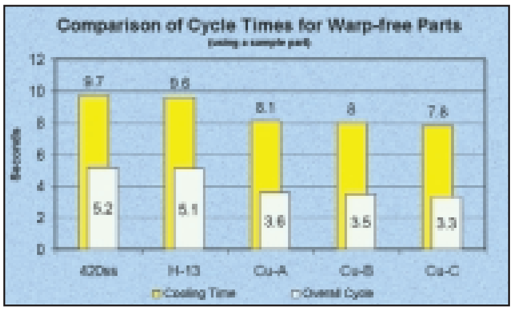
If drilled coolant channels are machined directly into the mold core, the edge of the coolant channel should be about two times the diameter away from the molding surface. The distance between the coolant channels should be from three to five times the diameter, see Illustration D. Positioning the coolant 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

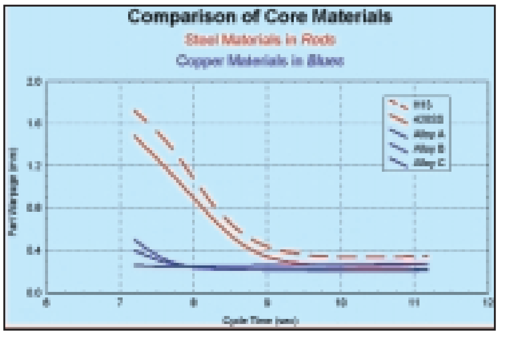
Extensive testing was conducted at Western Michigan University comparing the use of the three most commonly utilized copper alloys in injection molds C17200 (A), C17510 (B) and C18000 (C) against H-13 and 420 SS. A single cavity test mold for a 50-mm polypropylene closure was obtained and optimized to 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 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. This test was conclusive, confirming anecdotal experience from



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 Icompared to cycle time for copper alloys Vs tool steel.

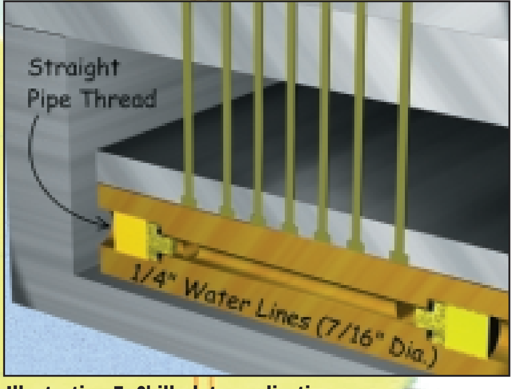


Illustration E: Chill plate application

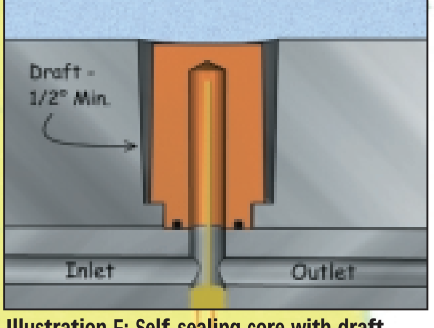


Illustration F: Self-sealing core with draft

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. ❐

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

For more information about the use of copper alloys in tooling, please write in 668 on the reader service card.