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)

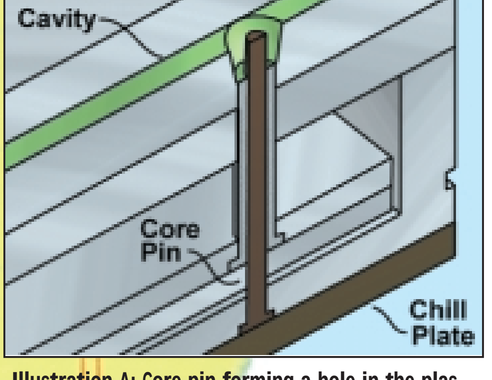

Illustration A: Core pin forming a hole in the plastic part. The core pin transfers heat to a chill plate for faster cooling cycles.

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-

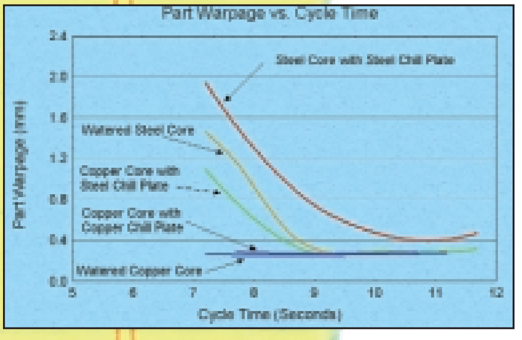

Chart B: Chart illustrates advantages of copper alloys in reducing part warpage and cycle times.

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

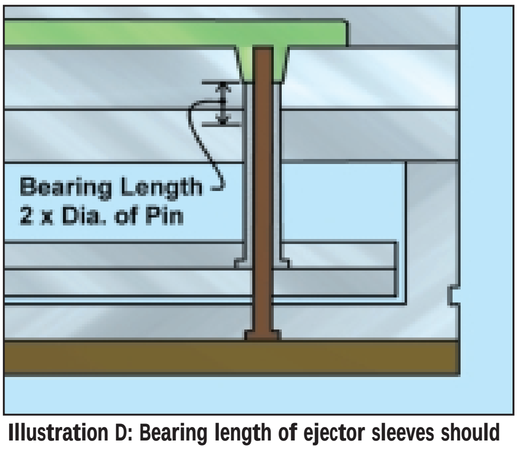

Illustration D: Bearing length of ejector sleeves should be no greater than two times the diameter.

contact surface is accommodated nicely by the high thermal conductivity of the copper alloys.

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-

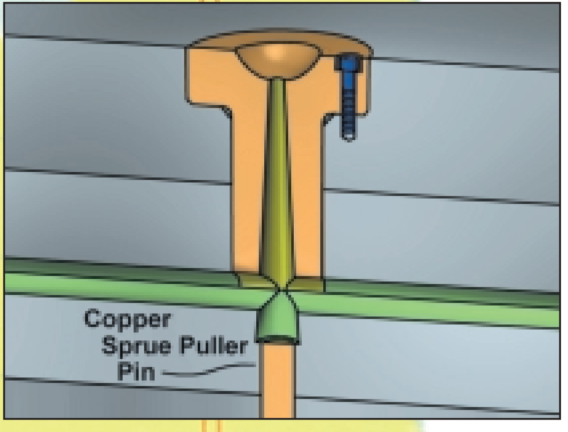

Illustration E: Copper alloy sprue puller pin used to firm up puller and reduce molding cycles.

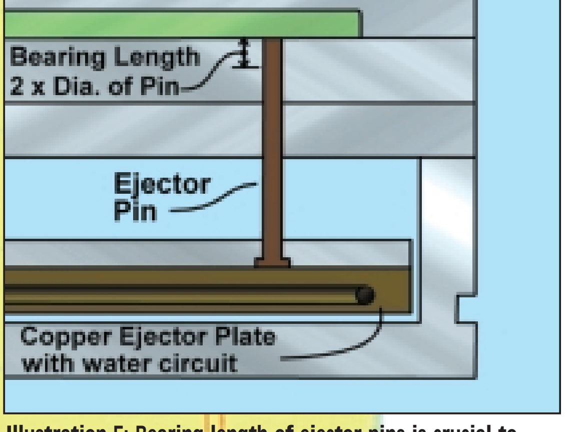

Illustration F: Bearing length of ejector pins is crucial to mold life.

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. ■

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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

For more information about the use of copper alloys in tooling, please write in 669 on the reader service card.