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Alloy Selection for the Injection Molding Industry

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Abstract

The use of C17200 beryllium copper alloys in mold cores and cavities has been evaluated for effectiveness in meeting material requirements and minimizing per part cost. The alloys have been compared to tool steels and as well as aluminum alloys. It has been found that beryllium copper alloys are capable of producing significant per part cost reductions via their excellent thermal characteristics which allow for decreased cycle times, reducing part overhead, while maintaining good hardness, limiting the need for mold repair and refurbishment.

1 Introduction

The molding industry, like any manufacturing industry, is continuously striving to reduce costs. The cost of a produced part is generally determined by three factors: the cost of the material required to produce the part, the cost of the tooling itself, and finally, the overhead cost, which includes everything that is required to keep the production facility running, such as utilities, labor, etc. The material cost is easy to conceptualize, and the tooling cost is arrived at simply by dividing the cost of tooling (both material and manufacture) by the number of parts it can reasonably be expected to produce before needing replacement. Overhead costs on the other hand are almost entirely dependent on the time required to produce a part, its cycle time.

Cycle time provides an ideal avenue for cost reductions. If cycle time can be decreased, then the overhead cost, which in the case of most molded parts is often the largest component of the overall cost, can be reduced, without any changes to the product itself. If this can be achieved, then the cumulative savings over a production run can be significant.

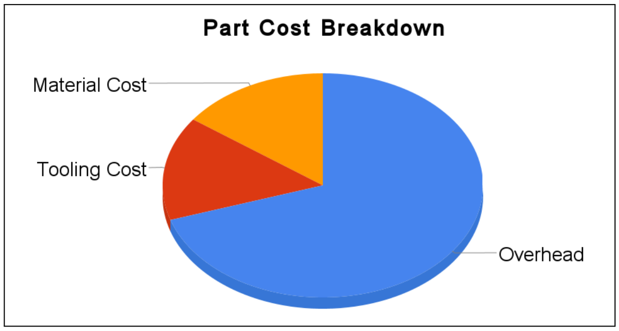

Figure 1: Material and tooling costs represent only a small portion of the per part cost in a molding operation. The overhead, which is directly related to the part cycle time is the driving factor.

2 Optimizing Cycle Time

The cycle time (T) required for producing a part is equal to:

$$T = 2O + I + C + E \quad (1)$$

where O is the time required to open or close the mold, I is the time to inject the material, C is the cooling time and E is the time required to eject the part [1]. In a normal injection molding operation the cooling, or curing time can represents as much

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as half or more of the total time to produce a part. This curing portion of the cycle time is nearly entirely dependent on the thermal conductivity of the cavity and core mold. Therefore, maximizing the thermal conductivity minimizes the curing time for the part which in turn, decreases part cost.

3 Material Properties

Besides decreasing cycle time, high thermal conductivity also increases the thermal homogeneity of the part during cooling which reduces warping. If a cavity and core have poor thermal conductivity, then hot spots can develop during the curing process. Hot spots are regions where the tooling temperature is higher than the surrounding material and the local cooling rate of the fabricated part will be lower than that of the rest of the part. This variability in cooling rate can lead to parts warping, yielding inferior and sometimes unusable products.

There are other crucial material properties to consider though, chief among them, the hardness of the material. A hard material reduces wear, improving longevity as it reduces the susceptibility of the mold to dents and scratches. Therefore, an ideal material for a cavity or core is really one that maximizes these two material properties. In addition to thermal conductivity, it is important to also consider material properties such as corrosion resistance, machinability and weldability amongst others.

In Figure 2, the thermal conductivity for materials commonly used for mold cores and cavities are compared. What is interesting is that while the steel (420, H-13 and P-20) and aluminum (QC-7, QC-10) products fall on a traditional trade-off line, where increasing thermal conductivity is achieved at the expense of hardness the C17200 products do not. There are two available tempers of the C17200 alloy: TF01 and TF02. The TF01 temper trades slightly reduced thermal conductivity for improved hardness, giving it even better wear characteristics than the TF02 temper which aims to maximize the thermal conductivity of the mold. In both the high hardness TF01 and low hardness TF02 forms, the C17200 alloy exhibits a far better combination of hardness and thermal conductivity than any of the other materials. It should be noted however that the aluminum alloys are too soft to be accurately represented on the HRC scale and therefore their placement is not exact.

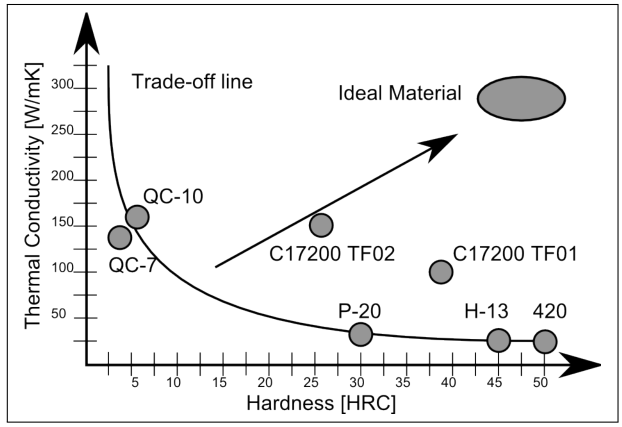

Figure 2: The ideal material for mold cores and cavities is one that has both excellent thermal conductivity and high hardness (note: the aluminum alloys have hardnesses below the effective range of the HRC scale)

The cost of the material used to make the core and cavity must, of course be considered and are given with thermal conductivity and hardness data in Table 1. The cost of the cavity and core material generally represents less than 15% [2] of the total part cost. The limited effect of tooling cost allows considerable leeway during the material selection process.

4 Mold Fabrication

The ease of machining of the various materials is difficult to quantify. In general however, the steels, particularly the 420 alloy can be quite tough to machine whereas aluminum alloys are easier and allow very high cutting speeds. The C17200 alloy on the other hand generally falls between the steel and aluminum alloys in terms of ease of machining. A slower cutting speed than that used for aluminum is necessary, though not as slow as the hard steels. Cutting speeds of roughly twice that of steel have proved reasonable.

Table 1: Thermal conductivity, hardness and cost data for various alloys used for mold cavities and cores. Due to the variability of market prices, cost is presented as relative numbers from 1 to 10 where 1 is a higher cost material and 10 is very low cost.

Material	[W/mK]	[HRC]	Rel. Cost
P-20	42	30	10
420	24	50	7
H-13	29	45	8
QC-7	138	80HRB	5
QC-10	159	165HRB	4
C17200 TF01	103	40	2
C17200 TF02	130	30	2

Table 2 gives point ratings for corrosion resistance, machinability and weldability for P-20, H-13 and 420 steel alloys as well as C17200 beryllium copper.

The soft nature of Aluminum alloys results in the lowest cost for mold fabrication, while steel and C17200 molds are slightly more expensive to produce due to slower cutting speeds and increased cutting tool wear. The apparent cost savings related to mold manufacture for aluminum alloys is deceiving however, as the softer cores and cavities are more damage prone and require repair or replacement at increased intervals, thus making them suitable for only small production runs.

Table 2: Point ratings for material properties from 1 to 10 where 10 is the highest [1]

Mat.	Therm. Cond.	Corrosion Resist.	Machin- ability	Weld- ability
P-20	5	2	5	4
420	2	6	4	4
H-13	4	3	9	5
C17200	10	4	10	7

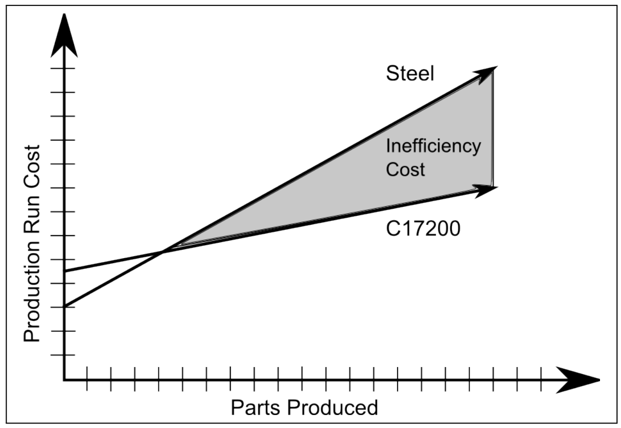

Figure 3: Selection of the wrong alloy for cores and cavities can result in significant lost profit due to the cost of inefficiency.

5 Materials Selection

Selecting the single best material for all molding applications is not realistic. Factors such as the number of parts to be produced, part geometry and part material all need to factor into the decision process. It is however, possible to make quite telling general observations. The quality of a produced part is dependent on the mold material's thermal conductivity and hardness. In this case Figure 2 shows that C17200 alloys provide a combination of thermal conductivity and hardness that is simply unmatched by either aluminum or steel alloys. Aluminum alloys and C17200 in its TF01 and TF02 condition provide the thermal conductivity necessary to produce parts with good dimensional tolerances, but the aluminum alloys don't have the necessary hardness.

It is important to not forget other material properties that affect the performance of mold tooling. Table 2 shows that in a number of important material properties the C17200 alloy has comparable or better scores than the competing steel alloys, aluminum alloys are not considered at this stage as they are simply not hard enough. The C17200 alloy requires a larger initial investment, but as indicated in Figure 3, in large volume production runs, this cost can very quickly be recuperated by the significant savings associated with the dramatically reduced cycle times and part warpage.

For smaller production runs, a hybrid of steel and C17200 can produce excellent results. In this case, steel cores and cavities can be produced, but C17200 inserts can be installed in regions where hot spots would occur the steel tooling. Increasing the thermal conductivity in these trouble zones can combat the tendency of the part to warp by increasing the cooling homogeneity.

6 Conclusions

Alloy selection for mold tooling is never easy and requires the balancing of a number of competing factors. It is apparent though that particularly when dealing with large volume or high precision production runs, dramatic savings can be had by employing C17200 alloy as opposed to steels such as P-20, H-13 and 420 or aluminum alloys. Furthermore, hybrid molds of steel and C17200 alloys can be produced, giving the small production run cost advantage of steel while still reducing the incidence of warped, unusable parts.

References

[1] D. V. Rosato and M. G. Rosato, *Injection Molding Handbook*. Massachusetts: Kluwer Academic Publishers, 2000.

[2] "Copper alloy molds: Benefits," tech. rep., Copper Development Association, http://www.copper.org/applications/ industrial/ CuMolds/ benefits.html, 2009.