Efficiency and Cost Tradeoffs Between Aluminum and Zinc-Aluminum Die Cast Heatsinks

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ABSTRACT

High purity aluminum has always been a good heatsink material for removing heat from electronic components. However, the manufacturing of specialty shaped, non-extrusion based heatsinks, causes many material-based problems.

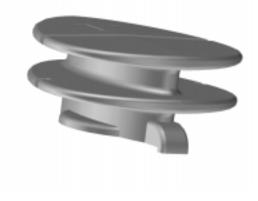


Figure 1 - Heatsink

High purity aluminum is very difficult to die cast and impurities must normally be added to aid in the die casting process. These small amounts of impurities cause the thermal conduction coefficient of the material to drop almost in half. The resultant thermal conductivity closely matches that of many zinc die cast materials.

A cost and performance analysis comparing die cost, per piece cost, efficiency drop between high and low power densities will be examined between various commercial zinc, zinc-aluminum, and aluminum die casting materials. This examination was performed in connection with the design of the cooling system for UNC's PixelFlow, the worlds fastest graphics computer that utilizes 44 custom chips, 5 watts to 55 watts per die. This 9 kW air-cooled system is very compact, and measures 18" by 42". Short, high-speed signal path lengths require an innovative and cost effective method of removing heat between the closely spaced chips and cards.

PROBLEMS IN HIGH POWER COOLING

With the higher power densities in computers and other electronic gear, the choices and ability to use off-the-shelf heatsinks diminishes. With low power, simple clip-on heatsinks can be effective, even up to three watts for power applications. For more formidable and heat sensitive components, such as processor chips, more expensive cast or extruded fin heatsinks are required. In the most expensive and difficult to cool electronic equipment, liquid, conduction or immersion cooling is required. These cooling systems are cost prohibitive to all but large scientific organizations and governments.

Unfortunately, the trend in power densities pushes the modern day electronics packaging group to the limits of current, affordable air cooling systems, requiring the use of commercially prohibitive liquid or conduction cooling methods. To remain commercially viable, air cooling system designers, must pay attention to the actual airflow of the system and the heatsink design.

When possible, off-the-shelf extrusions are inexpensive and effective for most moderate-to-higher power applications. However, when component density is fairly high, the inherent shortcomings of extrusions are revealed. They do not have very high thermal conductivity for their surface area and can have significant back pressure when many are located in series.

Figure 2 shows an image of the uncoolable rasterizer board caused by too much back pressure from the fin style heatsinks. This is an example of an early style off-the-shelf heatsink, at an average cost of \$2.50 apiece and which 44 are required per board. Figure 3 is the current board utilizing the custom zincaluminum heatsink shown in Figure 1 at a cost, including setup, of only \$0.73 per unit.

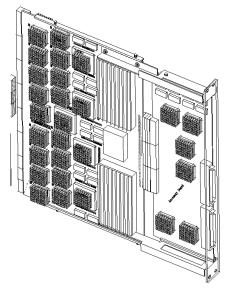


Figure 2 - Early fin style heatsink

A thermal simulation using FEA to determine airflow for chassis is in Figure 4. A complete airflow analysis at both the macro and single heatsink level is required for effective, high power cooling design. All it takes is one hot spot to ruin an other-wise good design. Airflow is from the left screen intake out through a 12" fan exhaust on the right.

When it is determined that heatsinks are required, it is time to look at the volume of the product and the quantities of heatsinks needed. If volume is low and there are a small number of components per board, off-the-shelf heatsinks will normally be the most economical choice. When an off-the-shelf heatsink is not available, a custom designed heatsink may be required.

When custom design heatsinks are necessary, the following options should be examined: machined parts (expensive, mostly for conduction cooled components in power supplies and military gear); aluminum extrusions (lower density, known air direction); cast / machined fins or stacked platter heatsinks (for omnidirectional air flow); or cast

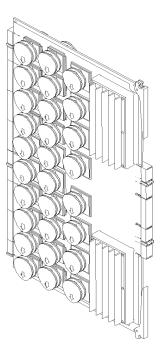


Figure 3 - Airfoil Zinc/AL Heatsink

heatsinks for low back pressure, higher volume designs.

A cast heatsink will obviously have a higher setup cost than an extrusion. However, this cost can be offset greatly by the flexibility of optimizing the cooling shape and the elimination of hand finishing and plating (in the case of zinc or zinc-aluminum material).

When it is determined that the need for a cast heatsink is required, a cost benefit analysis of the different materials should be conducted. When

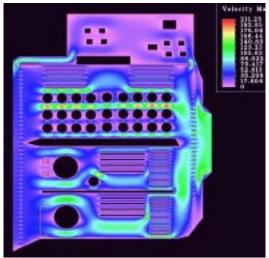


Figure 4 - Velocity Profile

aluminum is extruded for heatsinks, a pure, high quality aluminum with few additives is used providing 160 -180 W/($m^{*0}C$) thermal conduction. However, in the die cast process, a higher amount of silicon is required for the casting and the inherent porosity in die cast aluminum causes an appreciable drop in the thermal conduction to approximately 96 W/($m^{*0}C$), which is lower than the cheapest casting grade of zinc.

The process of pouring aluminum into hot dies and slow cooling, sometimes referred to as hot isostatic pressing results in a low porosity aluminum with a thermal conductivity roughly 50% higher than zinc. However, its production rate is much slower resulting in a higher piece cost and very little price drop for higher volumes as compared to die casting. Pricing of this process could be compared to that of permanent molding.

Aluminum also has the additional cost associated with its use that of the secondary operation of plating. Zinc and brass, also common heatsink materials, do not require this secondary process. However, brass has the same unfortunate casting properties as aluminum. Brass requires the addition of impurities to increase its castability. These impurities severely effect the thermal conductivity of brass. However, brass should not be overlooked, its poorer performance and high cost may be a necessary trade off when mating to a chip carrier with a low coefficient of thermal expansion.

MEDIUM VS.HIGH THERMAL CONDUCTIVITY

In designs of medium power chips (3 to 7 watts each) the temperature variation from the base of the heatsink to the fin edges may vary only a few degrees Centigrade. It is natural to want the highest coefficient of thermal conductivity. However, examination is required to determine whether a 3 $^{\circ}$ C temperature rise versus a 5 $^{\circ}$ C temperature rise in the heatsink is a concern. The die temperature may change from 80 $^{\circ}$ C to 82 $^{\circ}$ C. Is this worth the savings of \$1.00 per heatsink? In most cases, the cost savings of using the cheaper zinc or zinc-aluminum wins. In addition, a larger heatsink cast in zinc can be made to compensate for this lost performance while staying within one half the cost of poured aluminum.

Figure 5 shows the temperature gradient across a zinc/aluminum heat sink with 6 watts of heat dissipation. The image is upside town to show the actual die. The next layer is the brass cover on the chip carrier and bottom two fins and central core are the die cast heat sink. The total temperature gradiant

across the heatsink is less than 2 degrees ${}^{0}C$. If a machined or extruded aluminum part were used (and could be made to this complicated shape) the theoretical minimum temperature gradient would only be about 1 ${}^{0}C$.

It is important to realize where the biggest resistances are in the thermal dissipation path. In most air cooled applications, the case to air or heatsink to air temperature differential will be the biggest resistance problem, not the thermal resistance tape or internal resistances in the heatsink itself.

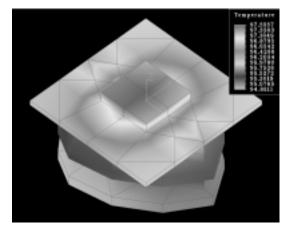


Figure 2 - Heatsink Temperature Gradient

Zinc is naturally low in porosity during the casting process. This is what makes a mediocre conductive material into a contender against the presumed high conductive materials. If a doping of 8% aluminum is added to the zinc, the properties more closely match the fine qualities of aluminum. Most notably, the thermal expansion drops to closely match that of most heat slugs on chip carriers.

The manufacturing cost of zinc-aluminum also has major advantages over all other cast heatsink materials in medium quantity ranges. The low pouring temperature allows for non-steel molds to be made reducing by one half the NRE charges. In addition, this lower temperature allows for a much quicker pouring cycle than aluminum.

The table below indicates the properties of the six different heatsink casting materials and their estimated costs using a 0.34 in³ (1.2 ounce zinc) heatsink as shown in Figure 1. Special attention should be given to the efficiency of the thermal conductivity material, and the thermal expansion to ensure compatibility with the mating chip carrier.

	Zinc	Zinc-	Zinc-	Aluminum	Aluminum	Brass
		Aluminum	Aluminum	poured	die cast	annealed
	Zamak 3	ZA-8 ^b	ZA-27 ^c	357	380	360
Tensile Strength	41,000	54,000	62,000	33,000	47,000	49,000
(PSI)						
Density	0.24	0.227	0.181	0.098	0.098	0.30
(lbs/in ³)						
Melting Point	718 - 728	707 - 759	708 - 903	1035 - 1100	1000 - 1100	1630-1650
(deg. F)						
Coef. of Thermal	15.2	12.9	14.4	12.1	11.9	11.4
Expansion (in/in °F)						
Thermal Conductivity	113	115	125	161	96.2	61
(W/m°C)						
Tooling Cost (\$)	\$8,000 -	\$8,000 -	\$8,000 -	\$20,000 -	\$20,000 -	\$20,000 -
	\$15,000 ^a	\$15,000 ^a	\$15,000 ^a	\$35,000 ^a	\$35,000 ^a	\$35,000 ^a
Material Cost	0.60	0.63	0.72	7.50 -12.00	7.50 - 12.00	10.00
\$ per pound						
Cost for part	0.40	0.41	0.48	1.25	1.20	1.60
run of 5,000 each \$						

Heatsink Material Comparison Table

Table Notes:

All prices are averages amongst several die casters for each process. Stronger weight of averaging placed by vendors who bid several different processes for same part.

- a) Second price is cost for four cavity molds. This would reduce "cost per part" and useful for large lots.
- b) ZA-12 (not listed) has a thermal conductivity that is 1.2% greater than ZA-8 and generally is not worth the cost premium for heatsinks.
- c) ZA-27 has a 9% greater thermal conduction coefficient than ZA-8. However, its thermal expansion coefficient is quite high and could cause problems when attaching to many chip carriers. It can be effectively used when attachment surface area is small and secured with fasteners such as TO220s and similar components.

SUMMARY:

When the design calls for a custom heatsink due to either economics of scale or specific performance, do not always feel that an extrusion is the only alternative. Castings allow for 3D heatsink geometries instead of 2D, allowing for more efficient and effective heatsink designs.

No common casting material can match the thermal conductivity of high purity extruded aluminum but zinc-aluminum materials such as ZA-8 are fairly close and the thermal conductivity efficiency advantages of a 3D design can outweigh the perceived impedances. Zinc-aluminum parts closely match the thermal expansion of most chip carriers and are much stronger than aluminum, and thus preventing exposed fins from being bent or damaged.

Low cost, high performance zinc-aluminum die cast heatsinks are recommended for high power production designs where weight isn't critical.

NOTES

This heatsink design and its manufacturing process design rights have been transferred to Hewlett Packard Corporation for use in their PixelFlow graphic super computer.

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Software used in the analysis: Algor 2D and 3D fluid dynamic and thermodynamic software running on HP 735 and C160 workstations, Excel, various, math solver programs and custom software.