Cast Heatsink Design Advantages

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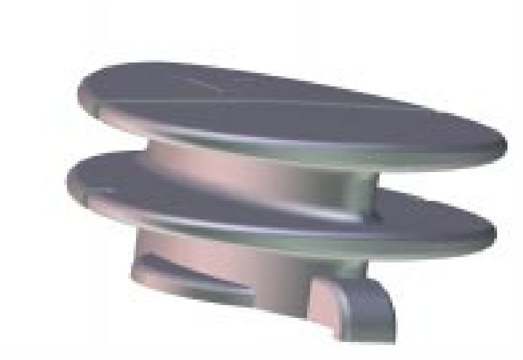

Figure 1 Die cast heatsink

ABSTRACT:

Power dissipation of chips has been raising faster than the technology needed to economically cool them. Especially in the high performance arena. To get high efficiency heatsinks presently, extrusions are machined or entire heatsinks are machined with strategically arranged fins. These methods are not as effective in high component densities or cost sensitive units compared to newer, porosity free castings.

Die casting of, low cost materials, especially aluminum doped zinc, creates a porosity free, low cost, efficient heatsink. Hand poured aluminum and brass alloys are also useful in special circumstances, but with a cost penalty. Airfoil shapes can be made to take full advantage of true 3D casting shapes and direct the airflow as required; this can greatly reduce back pressure by creating turbulence only where needed. Assembly clues such as arrows can be located along with stops and alignment pins. Even turbulence enhancing grooves and attachment points can be added with little per piece cost penalty.

Our particular design utilizes a zinc-aluminum material. Its shape was optimized from CFD & FEA thermal simulations for minimum backpressure and even heat distribution. Per piece cost is about $0.50 vs. $2.00 for machined. This investigation is based from the work of cooling PXFL, licensed to Hewlett Packard as the *Visualize PXFL*, the world's fastest graphics computer, dissipating about 450 watts per board. One of these boards is shown in Figure 2.

The cooling problem in this project stemmed from the electrical design requiring 3 closely spaced rows of processors 8 to 10 deep. Nine of these double-sided boards had to be placed sided by side with a spacing of only 50mm between boards. All to be forced air-cooled. The backpressure using standard fin or turned heatsinks was unacceptable.

A custom shape heatsink was designed which provided adequate cooling to all 44 processors mounted on both sides of the board while controlling the airflow to minimize backpressure. Because of its unique shape and requirements, much discussion with casters and molders were needed during its development.

1. ADVANTAGES TO CASTINGS VERSUS STANDARD HEATSINKS

When heatsinks are needed for discrete electrical components, a standard set of styles are called upon for the different requirements. Clip-on, stamped heatsinks are commonly used for power IC effectively. Extruded ones used on more powerful ICs, processors or power cans; sometimes with multiple components sharing the same heatsink. While machined heatsinks are utilized for high powered, forced air-cooled processors and other high value components.

This paper will introduce advantages of die casting heatsinks. The proper material selections for different applications and cues to help take advantage of the additional benefits that a 3D heatsink can provide versus standard 2D shapes.

Addition of assembly cues and marks

Assembly cues and aids can be molded directly onto a heatsink. Such items as arrows, part numbers and alignment pins can be easily placed in the mold. Clips and holders are also items that are easily molded in. In our example, we have included a recess for installing an optional wire tie down, assembly stop and alignment arrow.

Better aerodynamic and cooling efficiency

Heat sinks are most commonly made by these following methods: extruding, used most often in higher powered and amplifier type cooling; stamped, used in low power discrete component cooling; and machined, used in medium powered discrete component cooling, especially high value items like processors. This paper will focus on

Figure 2 Heatsinks mounted to printed circuit board

the last listed heatsink style where expensive machined heatsinks can be replaced by cast versions.

Cast heatsinks do not have the limitations imposed by extrusions from a 2-D profile nor the backpressure inherent in the saw cut, non-aerodynamic front end of an extrusion. In forced air systems, the squared shape entrance of a saw cut creates a large pressure build up region creating for much of the backpressure in the heatsink. The head-loss reduction for this improvement in entrance shape can be approximated by: a K of 0.4 to 0.5 for a sharp edge inlet to a K of 0.20 to 0.05 for a slightly round to rounded entrance (radius= 0.2*spacing gap)[1].

Figure 3 shows a high-density arrangement of heatsinks mounted to both sides of a circuit board. Notice on the side profile where air is designed to be trapped in channels between the boards. The airfoil shape of this heatsink helps maintain this airflow where turned machined or extruded versions created too much turbulence after passing so many heatsinks. As always, local turbulence on the heatsink is good but keep it laminar elsewhere.

[redacted]

Less post machining handwork

Die castings normally do not require deburring or secondary processes afterwards to clean up a machining operations as needed in cut extrusions or machined heatsinks. Drill holes are normally needed for mounting extruded heatsinks; however, in cast heatsinks, these can also be integrally molded in.

	Extrusion	Die Casting
Minimum standard fin thickness	1.5 mm	1.8mm
Fin height to thickness ratio	5:1 standard 10:1 with wide fin spacing	5:1 on plunger axis 20:1 perpendicular to plunger
Fin height	Limited to extrusion die size	Limited to die chamber
Draft angle	None needed – 2D	2^{o} to 5^{o} for >12mm features
Finish	125-64 rms	125 rms
Post process	Cutting & deburring cut edge	None

Table 1 Design guidelines / variations between casting and extruding

2. MATERIAL SELECTIONS

It is commonly believed that very high thermally conductive materials are the only types of material that can be used for heatsinks. This is generally a misconception. Even with medium powered chips of about 5 watts, the temperature only rises about 4 °C from die to surface of the heatsink $\theta_{JC\ (case\ being\ heatsink\ surface)}$ in our example (figure 3) of a zinc heatsink casting in the ultra dense PXFL computer. The airflow is about 3 m/s with a ΔT_{JA} of about 54 °C or θ_{JA} 11 °C/W.

A machined aluminum heatsink of the same geometry only reduces the die temperature by about 2 more degrees. A cast aluminum one is about the same as the zinc. In the moderate power ranges, it is the surface area and the heatsink geometry where most of the heatsink efficiency is gained.

The perceived problem of resistance of the heatsink material being a major factor of natural or forced air cooling at this power level is only about 5% of the total resistance. Most is in the exchanges from fin surfaces to passing air. Much cost savings in the heatsink can be saved by using cheaper materials or manufacturing methods that only effect a few percent of the entire heatsink efficiency.

Aluminum alloys

Aluminum is the most common material used as a heat sink or conducting material and for many good reasons. It has an exceptionally high thermal conductivity. It is easy to form and fairly easy to machine; although, not nearly as easy as free machining aluminum which has more silicon and other alloys to increase strength and machinability but with a substantial penalty to thermal conductivity. Aluminum is also quite light for a highly thermal conductive material.

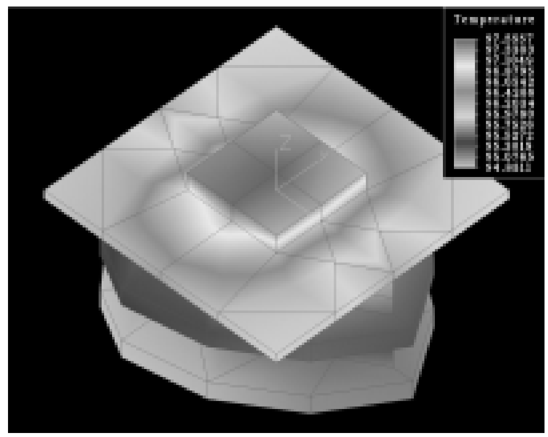

Figure 4 Heatsink temperature gradient

Secondary processing

Like all materials, there are drawbacks. Secondary processing is required on all aluminum heatsinks used in electrical equipment. This is a plating required for UL approval. Raw Aluminum would oxidize creating an insulating film that can be easily rubbed down onto the conductive surface. This leaves a danger of rubbing wires causing potential shorts.

Porosity

For casting, aluminum has some other inherent disadvantages. These mostly stem from aluminum's poor die casting ability when in a pure state. Aluminum must have a couple percent of silicon added to allow it to slip out of a mold easily. Unfortunately this causes the internal structure of aluminum to be non-homogeneous which reduces its thermal conductivity to about 1/3 of pure aluminum. Porosity inside the casting forms resulting in poor material contact, greatly increasing the thermal resistance inside the casting.

Reducing porosity

A method called Hot Isostatic Pressing helps to alleviate this porosity problem by hand pouring and pressing under low pressure instead of high die cast pressures but this still has only ½ the conductivity of raw aluminum; the cost of this method is also 2 – 4 times higher than standard die casting. However, it may be economical advantageous in systems with strict weight limitations – specifically avionics and portable electronic equipment.

Copper alloys

Brass and bronze are two not as frequently used materials for thermal dissipation. Pure copper has an extremely high thermal conductivity but, even to a more extreme than aluminum, the impurities needed to make casting or machining possible drop its conductivity dramatically. It can be seen in Table 2 how these impurities drastically effect the thermal conductivity of copper. The most common copper heatsink used is a pure copper slug used as a heat spreader on chip carriers. Many medium and high powered chip carriers utilize this effective method. On top of this slug oftentimes a heatsink will be mounted to add more surface area for additional cooling. The heatsink / slug / die in Figure 4 contains an intermediate copper slug. This slug is normally plated to prevent oxidation.

For large heatsinks in corrosive environments where abrasion can occur or strength is required, bronzes are sometimes used. Most prevalently in marine environments on commercial gear.

	Pure Copper	Aluminum Bronze	Bronze	Red Brass
Conductivity	386 W/(m^{o}K)	83 W/(m^{o}K)	26 W/(m^{o}K)	61 W/(m^{o}K)
Composition	100% Cu	95% Cu, 5% AL	75% Cu, 25% Sn	85% Cu, 9% Sn, 6% Zn

Table 2 Copper alloy comparison

Zinc alloys

Zinc, with its good thermal conductivity (112 W/(m^{o}K)) but not great compared to pure aluminum (204 W/(m^{o}K) can often be overlooked as a heatsink material. In weight sensitive equipment, this oversight may be acceptable but in most other electronic cooling applications, especially medium to high volume, zinc alloys may have some added benefits over aluminum. Several zinc alloys have unusual properties which make them rather attractive for cast heatsinks.

Porosity free castings

Even with alloys added to zinc to help in strength, durability and castability, zinc maintains porosity free in the casting process. This results in thermal conductivity loss of a much less degree than aluminum or copper. In fact, its cast thermal conductivity exceeds that of most cast aluminum and copper alloys.

Low cost

Zinc, sometime referred to as pot metal, is known as a low cost material for casting. In the electronic manufacturing industry, it is used extensively in high tolerance motor castings, electronic mounts and brackets and even switch housings. Places where aluminum castings are also used where weight is a premium but at a penalty of 2 to 3 times the cost of a zinc alloy die cast.

Low pouring temperature

Die casting always entails much more tooling costs up front than an extrusion or machined heatsinks. Aluminum die casts can be quite high since the mold must be machined out of steel. Lower melting temperature zinc alloys (the high thermal conductivity ones that we are interested in) have the mold made out of easily machined aluminum, saving about 50% on the mold cost. Greater savings can be made by utilizing carbon molds; although these have an effective life of only about 60,000 parts.

Plating free

Underwriter's Laboratory requires plating on aluminum whereas zinc is not required since it does not create a non-conductive film on its surface[2]. This translates into lower overall costs by eliminating secondary manufacturing steps.

A comparison of different casting materials for same heatsink:

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

Table 3 Heatsink Casting Materials Comparison

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 TO-220s and similar components.

As can be seen when selecting a zinc alloy, ZA-8 has a thermal expansion match close to many ceramic and copper backed chip carrier packages. Even though its thermal conductivity is less than that of ZA-27, or not shown ZA-12, the problems associated with thermal expansion mismatch can cause stress problems down the road from this expansion difference.

Note "a" also specifies pricing for four cavity molds. Multiple cavity molds should be looked at when very large volumes of heatsinks are required or when the process times require such. When casting aluminum, there is a certain amount of cooling time required to let the core solidify more which results in a better thermally conductive heatsink. This cooling period takes up a significant amount of time on very expensive die casting machines. Because of this, it is economical to produce multicavity molds even for runs of as low as 20,000 parts. The cooling of zinc alloy in the die is relatively quick partly due to its lower melting temperature – smaller temperature differential change. This results in a much faster die casting time, benefiting in reduced costs per part. Single cavity molds are most economical for most zinc alloy castings until casting volumes pass 60,000 or so.

Also obvious from the above, compiled chart is the variation of weight in the casting materials. This should be noted in the material costs per pound calculations. Zinc and its alloys are quite heavy and as mentioned previously, do not make good heatsinks for portable equipment. For portable equipment look into cast 380 series aluminum and where very high power densities are required, investigate hot isostatic pressing with 357 or similar series aluminum.

3. SUMMARY:

Cast heatsinks give discrete chip cooling an economical and efficient heatsink. The shapes allow for manufacturing cues, reduced backpressure in the system and reduce the cost of heatsinks to about 30% of standard extruded or machined ones.

Die casting materials for heatsinks come in many different variations that need to be optimized for their particular use. Zinc with a moderate amount of aluminum doped in provides an extremely good heatsink material with compatible thermal expansion characteristics with most chip packages at an low per piece cost. Poured aluminum castings create complicated, lightweight shapes cheaper than machined versions and are better tailored to portable equipment.

4. ACKNOWLEDGMENTS

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

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