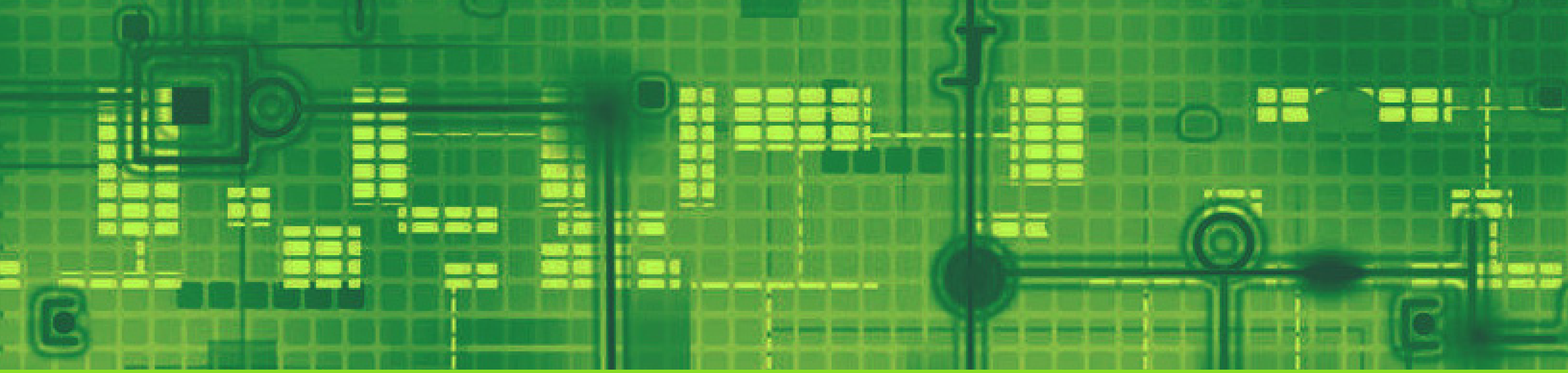

Heat Sink Manufacturing

Using Metal Injection Molding

Rapid developments in microprocessor technology have led to a need for the efficient high-volume production of advanced heat sink devices. The metal injection molding (MIM) process is highly suited to the production of the next generation of these high performance products. Similar to plastic injection molding, MIM offers product designers a greater freedom to adapt traditional heat sink designs, in order to offer both increased thermal efficiency and substantial cost savings in high volume production.

The current attention on thermal management systems has become more intense with the increasing speed of modern microprocessors, higher performance workstations and memory chips. Power density in these micro devices has increased significantly over the past decades, so the manufacturing of more complex designs needs to develop in order to meet the new challenges [2].

In the early days, a passive heat sink with a cooling fan was sufficient to remove heat efficiently from many electronic devices. Later, heat pipes became the popular design application and, today, advanced cooling systems such as liquid cooling, thermoelectric cooling and even refrigeration are showing stronger presence in the market.

Regardless of the cooling systems, there is always a basic need for a heat sink or heat spreader to come in contact with the heat source, in order to conduct the heat away.

Historically, manufacturing methods such as die casting, extrusion and machining were familiar to many thermal engineers. It is only in the last few years that metal injection molding (MIM) has gained a foothold in the thermal community and its salient advantages have become more evident. The MIM process allows intricate features to be added into the heat sink design to boost thermal performance and its production process is very scalable compared with machining. Injection molding enables complex parts to be formed as easily as simple geometries, thereby allowing increased design freedom. MIM can meet the tolerance requirements for heat sinks without the need for secondary operations, such as machining. Producing net shapes allows considerable savings, since no material is wasted. Several thermal conductive materials, such as aluminum, copper, tungsten-copper and molybdenum copper, can be processed via MIM to meet some of the requirements. In this article, we are going to discuss the merits of copper material in the MIM process.

Metal Injection Molding Process

The MIM process consists of four basic steps (Figure. 1)[2]. First, metal powders and a polymeric binder are blended and mixed to form feedstock. Second, the feedstock is fed into an injection molding machine to form into any desired geometry, just as in plastic molding. Third, the molded part is placed inside the low temperature oven, with controlled atmosphere and heating

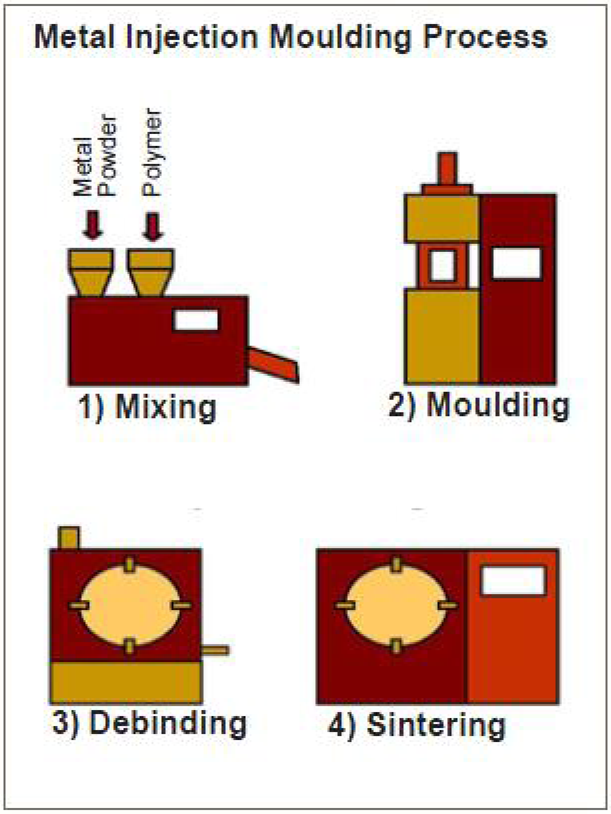

Figure 1. Metal Injection Molding Process [2]

rate, to remove the binder, leaving behind the powder skeleton structure of the original shape and size. Finally, the debound part is sintered in a high temperature furnace to achieve a net-shaped, full density metal part. Secondary operations such as machining, coining or surface treatment may be required later depending on the design requirements.

MIM of Copper

The use of copper dates back thousands of years to early civilizations for the production of tools. Today, the high demand for copper is due to its excellent thermal and electrical conductivity and it is widely used in the thermal management, telecommunication, transportation and computer industries.

Copper is difficult to extrude, stamp, machine or cast but it is more commonly processed using the standard press and sinter powder metallurgy (PM) process. In the thermal management industry, performance and cost are important factors in design consideration; however, thermal engineers need to strike a fine balance between these two factors. For example, a diamond is desirable, as it has excellent thermal performance, but the high cost puts off many potential buyers; thus, its usage is confined to unique high-end applications. On the other hand, zinc and aluminum are cheaper and affordable but, because of their limited thermal conductivities, they have difficulties coping with the increased thermal discharge from powerful modern microprocessors.

This is where copper is a good fit to meet current needs. While the copper price is higher than that of aluminum and zinc, its thermal conductivity is almost twice that of aluminum. To mitigate the material cost, the MIM process is able to utilize copper efficiently by offering near net-shaped geometry, unlike the machining process. The thermal and mechanical properties of MIM copper are also as good as machined bar stock. This makes the MIM processing of copper an attractive candidate in modern heat sink / cold plate fabrication.

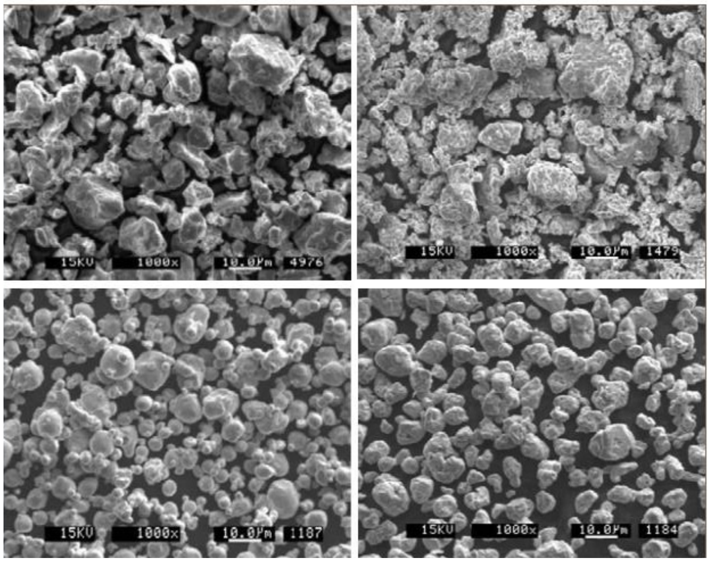

Figure 2. SEM's Of 11 µm Oxide-Reduced (Top Left), 15 µm Water-Atomized (Top Right), 8 µm Gas-Atomized (Bottom Left), 8 µm Jet-Milled) Bottom Right Copper Powders [2]

To sinter copper to high density with good metallurgical properties, oxygen and metallic impurities must be care¬fully controlled during the processing. Bulk oxides in the copper powder must be completely reduced, before pore closure, in order to achieve densities above 95%. Otherwise, water vapor can build up inside the closed pores, inhibiting densification and even leading to swelling. When this happens, the shrinkage control is inconsistent and leads to poor dimensional tolerances. The sintered properties are also compromised. Metallic impurities such as Tin (Sn) and Lead (Pb), in small traces, have less effect on the thermal conductivity of copper. However, Iron (Fe) impurity has a greater influence. To achieve a high thermal conductivity, both the final oxygen content, the solubility of oxygen in copper as well as the iron content, need to be below about 0.05 %[3],[4].

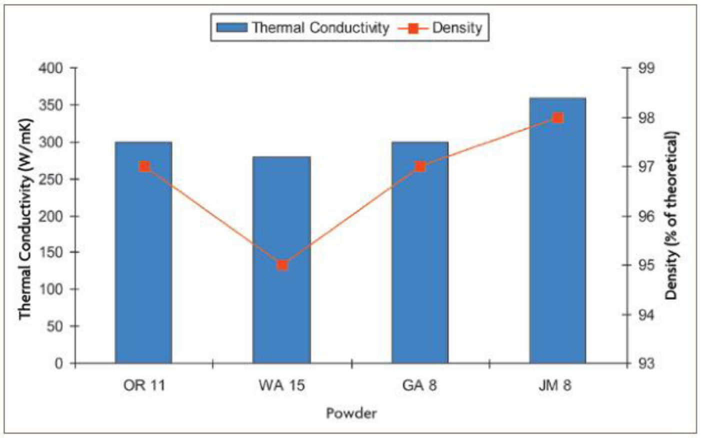

Figure 3. Effect Of Copper Powder On Density And Thermal Conductivity [2]

Copper powders for MIM application can be produced by several processes, including oxide reduction, water atomization, gas atomization and jet milling; all are commercially available in a wide range of particle shapes and sizes, as shown in Figure 2. The selection of copper powder is important and can have a significant impact on the sintered density and thermal conductivity. Figure 3 shows the properties of copper powders with mean particle sizes ranging from 8 to 15 µm. Performance and cost are two key considerations in deciding on the type of copper powder used to meet a specific need.

Thermal conductivities ranged from 280 W/mK for the water atomized powders to 360 W/mK for the jet milled powder. In comparison, the thermal conductivities of commercially pure wrought copper alloys can reach 380 W/mK, if they are electrolytically refined to limit metallic impurities to less than 50 ppm. Commercially pure cast copper alloys, which are the common source for many heat sinks or heat spreaders, have lower thermal conductivities, usually around 300-340 W/mK, because of the use of deoxidizers such as silicon, tin, zinc, aluminum and phosphorus.

Porosity and traces of metallic impurities, especially iron, in the sintered samples are the primary factors that control the thermal conductivity of MIM copper. Measured data of key properties of MIM copper is essential for real-life design planning and reliability prediction instead of depending on theoretical data from technical handbooks or literature. For thermal applications, sintered density and thermal conductivity are of great interest to the thermal designer, as accurate information can be inputted for the computational modeling of a heat sink design [5], [6].

As MIM technology offers flexible 3-D geometry and high quality material properties, heat sink design can leverage MIM's unique capabilities to give the extra edge in terms of performance. A typical heat sink usually consists of a base with one or more flat surfaces and an array of comb or fin-like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipation rate. In forced air convection mode, a fan is mounted directly over the heat sink to remove the heat quickly. In liquid cooling mode, fluid comes in contact with the fins to carry the heat away. By using the conventional metal working techniques on copper, the fin geometry is commonly straight, square or round in the case of Figure 4. In MIM, the technology allows the optimum design of fin geometry to maximize heat transfer. Fin designs

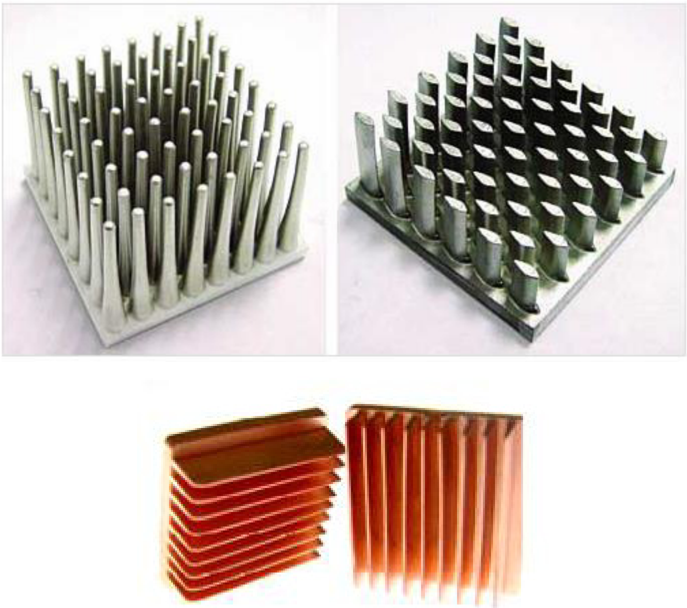

Figure 4. Examples of Heat Sinks Made Using MIM Process [2], [8]

such as round, elliptical, oval, diamond or even combination of all these, depending on where the hotspot is, are made possible by the MIM process. Some examples can be seen in Fig 4.

Today, there are already several thermal cooling systems on the market that make use of MIM copper heat sinks to remove heat efficiently, especially in the latest high-end PC models and workstations. The MIM process is a proven and well-accepted manufacturing technique for thermal management products. It is also very scalable and adaptable to volume change. This makes the MIM process an attractive manufacturing technique in the competitive electronics market where time-to-market, quality and cost are important.

In summary, metal injection molding is a net-shape manufacturing process that allows the fabrication of unique geometric features that are difficult to produce with other metal-working technologies. MIM technology offers an excellent opportunity for thermal engineers to leverage competitive advantages in designing the next generation of not only heat sinks but complex cold plates and heat exchangers. The cost and the performance of MIM heat sinks depend on the optimal use of copper powder grades and a processing technique to achieve good density and thermal proper¬ties. Thermal conductivity is one key performance indicator for the thermal industry. To every thermal engineer, the dream is to have the highest thermal performance at the lowest cost. The MIM process has the potential to give the best optimal results in the cost/performance matrix, especially for high volume production.

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