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# Heat transfer measurement of the cylindrical heat sink with sintered-metal-bead-layers fins and a built-in motor fan ☆

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ABSTRACT

This work sintered 0.5–0.85 mm-diameter copper beads smoothly with the radial plate fins of the copper heat sink by thin layers at high temperature to form a LED cooling device with sintered-metal-bead-layer fins. A motor fan could be installed or un-installed into the heat sink, which would result in the mixed convection heat transfer or the pure free convection heat transfer conditions, respectively. This work also experimentally investigated the effect of the sintered-metal-bead layers on the total heat transfer under the above-mentioned two heat transfer conditions. The experimental groups were the plate-shape sintered-metal-bead (Model B) and strip-shape sintered-metal-bead heat sinks (Model C). The pure copper finned heat sink (Model A) was set as the control group. The results demonstrated that the thermal resistances of the Model B and Model C were separately 29% and 16% higher than that of the Model A at the temperature difference between the heated surface and the ambient ($\Delta T$ 30 °C) and the pure free convection heat transfer condition (i.e. the heat sink without motor fan). It reveals that the present sintered-metal-bead layers cannot strengthen the free convection heat transfer. However, by comparing with the heat sinks without motor fan, the Model A, Model B and Model C built-in a motor fan had lower thermal resistances reduced separately by about 58%, 78% and 50%. It validates the effect of the built-in motor fan on the heat transfer enhancement, especially for the Model B with the plate-shape sintered-metal-bead layers. The thermal resistance of Model B was 31% lower than that of Model A at the mixed convection heat transfer condition (i.e. the heat sink with a motor fan).



## 1. Introduction

The dissipated heat of the chip used in the present electric equipment is growing and the volume of the chip is decreasing. The average heat flux of the chip was about 50 W/cm$^2$ in 2010 and raised to be around 250 W/cm$^2$ in 2012. This continuously increasing dissipated heat results from the trend of the recent electric products to be smaller and more functional. It is predicted that the working temperature of the chip will reach near the surface temperature of the sun till 2015. Therefore, the requirement of cooling design is more and more necessary.

Porous metal has been demonstrated that it can enhance the forced convection heat transfer strongly. Hwang and Chao [1] and Hwang et al. [2] measured the heat transfer capacity of the channel filled with sintered copper beads. Their experiments included the thermal entrance region and the thermal fully developed region. They also performed numerical simulations by using the Two-equation Model as well as considering the wall-function and cross thermal dispersion effects. They found that the inlet thermal boundary condition influenced the numerical simulation remarkably. Hsieh and Lu [3] numerically investigated the thermal characteristics of the sintered porous channel. They indicated that the Two-equation Model would underpredict the heat transfer performance if the cross thermal dispersion effect will not be considered in the thermal entrance region. Jiang et al. [4] numerically explored the forced convection heat transfer of air or water through the parallel-plate channel fully filled with sintered bronze beads. Their results indicated that the sintered metal beads promoted much more heat transfer than the packed metal beads due to the smaller local porosity of the former at the near-wall region. Jiang et al. [5] also used the experimental method to study the previous work [4]. The experimental results demonstrated again that the sintered porous materials had the excellent heat transfer capacity since their effective thermal conductivity is relatively high. They indicated that the heat transfer capacity of the sintered-bronze-bead channel is 15 and 30 times that of the empty channel separately by using water and air as the coolant. Tzeng et al. [6] experimentally discussed the effect of bead diameter on the forced convection heat transfer of sintered porous material. They indicated that the sintered porous material of smaller bead diameter was desired by the higher heat transfer requirement. Jeng and Tzeng [7] ever studied

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**Nomenclature**

| | |
|---|---|
| $A$ | heating surface area ($m^2$) |
| $D$ | diameter of film heater (m) |
| $I$ | input current (A) |
| $Q$ | heat (W) |
| $R$ | overall thermal resistance (°C/W) |
| $T$ | temperature (°C) |
| $V$ | input voltage (V) |

*Greek symbols*

| | |
|---|---|
| $\Delta T$ | temperature difference between the heating wall temperature and the ambient temperature (°C) |

*Subscripts*

| | |
|---|---|
| 0 | the ambient environment |
| Loss | heat loss |
| plate | horizontal plate |
| t | total |
| w | heating wall |

the heat transfer of the sintered-brass-bead block under the confined slot air jet by using numerical method. The simulation results depicts that the sintered-brass-bead material was better than the al-foam material in heat transfer. The smaller the height of the porous block was, the better the heat transfer performance was. Singh et al. [8] found the very good heat transfer performance of water through the sintered-copper-bead material. Tzeng [9] experimentally investigated the heat transfer of the 0.97-porosity aluminum foams inserted with the sintered metal and solid cylinders. He indicated that the thermal conductive cylinder was useful in the spatial thermal management. Bhattacharya and Mahajan [10] inserted the aluminum foams into the space between the plate fins of the finned heat sink and measured the heat transfer of this novel heat sink. They found that this novel heat sink did an excellent cooling device since the high-conductivity aluminum-alloy plate fins helped efficiently in conducting heat upward and transferring heat to aluminum foams, thus enhancing the total heat transfer. Rizk and Kleinstreuer [11] numerically simulated the thermal behavior of the porous channel with discrete heating blocks. They said that the porous material could enhance heat transfer by 50%. Jeng and Tzeng and their research colleagues [12–14] inserted the metal blocks or the single metal cylinder into the sintered porous or aluminum foam heat sinks. The high-thermal-conductivity solid metal would extend the heating surface into the internal porous structure, raising the effective fin efficiency and promoting the overall heat transfer.

This study developed and manufactured a finned heat sink with thin sintered-metal-bead layers. The heat sink, having the circular-cup-shape base with many radial plate fins, was made of copper. Using the high-temperature sintering technology, the plate-shape and the strip-shape thin sintered-bronze-bead layers were sintered onto both sides of each radial plate fin. The diameter of the bronze beads was 0.5–0.85 mm. A small motor fan could be installed into the chamber of the heat sink to form the mixed convection heat transfer, or not installed to result in the pure free convection. This work experimentally measured the heat transfer characteristics of the above-mentioned heat sinks. The main objective is to understand whether the thin sintered-bronze-bead layers enhanced the total heat transfer of the finned heat sink or not.

## 2. Manufacture of heat sinks and thermal-performance test

### 2.1. Design and manufacture of heat sinks

This work designed the finned heat sinks with thin sintered-copper-bead layers as Fig. 1. There were three kinds of heat sinks: (1) Model A heat sink without any porous layer, (2) Model B heat sink with plate-shape sintered-bronze-bead layers and (3) Model C heat sink with strip-shape sintered-bronze-bead layers. All the heat sinks had both non-perforation and perforation types separately for uninstalled and installed motor fan. Total 48 3 mm-diameter perforations were distributed uniformly at the cylindrical surface of the perforation-type heat sink. The dimensions, rated power and maximum flow rate of the motor fan herein (SUNON EB40101S2-0000-999) are 40 × 40 × 10 mm, 1.08 W and 7.0 CFM, respectively. The square frame of the motor fan would be grinded to fit the chamber of the heat sink.

The normal temperature that can sinter the bronze beads and the copper fin together is 800–890 °C. At the early stage of the trial-manufacture period, the finned heat sink was made of brass; the sintering effect was bad till 900 °C sintering temperature. The failed sintering product is as shown in Fig. 2. The bronze beads could not be sintered with the brass heat sink well. It is because the zinc is an element of the brass alloy. The melting point and boiling point of zinc are about 420 °C and 900 °C, respectively. When the sintering temperature exceeds 900 °C, the zinc is evaporated and then destroys the affinity between the bronze beads and the finned heat sink, weakening the structure strength of the sintered-bronze-bead layer.

According to the failed experience, this work selected the pure copper as the base material of the finned heat sink. The milling machine was used to fabricate a cup-shape cylinder with a 40 mm height, a 70 mm outer diameter and a 50 mm inner diameter, and then the electrical discharge machining technique was used to manufacture six radial plate fins . The stainless steel mold for sintering was also designed and manufactured by ourselves. The overall sintering procedure is as shown in Fig. 3. Firstly, the release agent was spread uniformly on the inner surface of the stainless steel mold, then the 0.5–0.85 mm-diameter bronze beads were filled into the mold, and finally the mold was put into the high temperature sintering furnace. The 890 °C temperature will melt each bronze bead and the surface of the finned heat sink, thus the bronze beads can be sintered to be the thin porous layers which adhered with the copper fins.

### 2.2. Heat-transfer experiment

In order to understand whether the sintered-bronze-bead layers enhance the convection heat transfer of the finned heat sink or not, this work built an experimental platform to perform the relevant heat transfer tests. The experimental setup, as shown in Fig. 4, was divided into three parts: (1) the heating system; (2) test specimens; and (3) data acquiring system. The heating system used the DC power supply to provide the electric heat to the foil heater as the dissipated heat from the chip of the electric device. The foil heater was adhered between the test specimen and the Bakelite base by using the high-conductivity thermal grease (OMEGABOND 200, k = 1.385 W/m °C). There were three kinds of test specimens used herein (see Fig. 5): (1) Model A: the finned heat sink without any porous layer; (2) Model B: the finned heat sink with plate-shape thin sintered-bronze-bead layers; and (3) Model C: the finned heat sink with strip-shape thin sintered-bronze-bead layers. The finned heat sink, having the circular-cup-shape base with many radial plate fins, was made of copper. The foil heater could heat the test specimen. The TT-T-30SLE T-type thermocouples were adhered on the back surface of the foil heater through the Bakelite base. The Bakelite base could reduce the possible heat loss from the foil heater.