International Communications in Heat and Mass Transfer 66 (2015) 226–232

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Thermal performance of an innovative heat sink using metallic foams and aluminum nanoparticles—Experimental study☆

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ARTICLE INFO

Available online 26 June 2015

Keywords:
Heat sink
Thermal performance
Metal foam
Nanoparticles

ABSTRACT

This paper presents an experimental investigation of thermal performance for four types of heat sinks. The investigated heat sinks were: extruded uncoated longitudinal fin heat sink, extruded coated longitudinal fin heat sink by aluminum nanoparticles, rectangular block of commercially available aluminum metallic foam, and the innovative heat sink using water as a working fluid with the velocity of 1.17 m/s, aluminum nanocoated metallic foams, and uncoated metallic foams. Each heat sink was cooled by a confined stream of ambient air. The experiments were done in a wind tunnel where the free stream velocity ranged from 1 m/s to 3 m/s. Temperatures were measured at the base of heat sinks to represent the Application Specific Integrated Circuits (ASIC) chip temperature. The effects of air flow velocity on the thermal resistance of the heat sinks were also investigated. The thermal resistances of the four heat sinks were compared as well. The results showed that the innovative heat sink with aluminum nanoparticles had the best performance in comparison to the above mentioned heat sinks used for the study. Although the metallic foam heat sink had better performance than uncoated heat sinks, it cannot be an economic replacement for industrial applications due to its high price and dirt absorbing property.

1. Introduction

In the past twenty years, transport phenomena in metallic foams and nanocoating ones have received growing improvements [1–8]. High porosity metallic foams have been applied in many technological devices [9]. For instance, a large variety of metallic foams have been utilized in geothermal systems, aerospace systems, and in petroleum reservoirs [10]. Thermal applications of foams consist of compact heat exchangers for air-cooled condenser towers, airborne equipment, and heat sinks for electronic devices [11]. Metallic foams have also been utilized as thermal conductivity enhancers of phase change materials (PCM) in thermal control equipment [12]. The open high porosity (usually more than 0.9), high thermal conductivity of the solid ligaments, the large embedded surface, and the ability to perform high-level mixing in the cooling fluid are the most important parameters that make metallic foam heat exchangers efficient, compact, and light-weight [12,13].

Generally, open-cell metallic foams include irregularly-shaped flow passages [13]. Convection heat transfer happens between the cooling fluid and the surface. The flow re-circulates at the back of the ligament. The geometric complexity and the random orientation of the foam solid materials make the solutions of the governing transport equations of the pores difficult [14–18].

Different studies have focused on the performance of heat sinks and metallic foams. Fiedler et al. [19] studied the thermal resistance of M-pore copper foam numerically and experimentally. Finite element analysis was used to calculate the thermal material resistance. The same samples were used for experimental analysis. The results showed that the thermal resistance depends on the size and the particular shape of the specimens. De Jaeger et al. [20] investigated the resulting thermal contact resistance for four bonding methods in an open-cell aluminum foam. They minimized the difference between the experimental data and calculated heat transfer via a Zeroth order model. Wang et al. [21] studied he thermal resistance of a heat sink with horizontal embedded heat pipes. They measured the thermal performance of a heat pipe and also the thermal performance of a heat sink with and without the function of heat pipes. Naphon and Wiriyasart [22] studied six mini-rectangular fin heat sinks with two different types of materials and three different channel widths. They considered the influence of the channel width, coolant flow rate, material type of heat sink and run condition of the PC on the CPU temperature for the purpose of improving the cooling rate of the electronic equipment. Lin et al. [23,24] studied the effect of fan speed on thermal resistance. The results indicated that a heat sink with a maximum fan speed of 4000 RPM has an optimum total thermal resistance value of 0.33 °C/W. Xie et al. [25]

☆ Communicated by W.J. Minkowycz
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http://dx.doi.org/10.1016/j.icheatmasstransfer.2015.06.007
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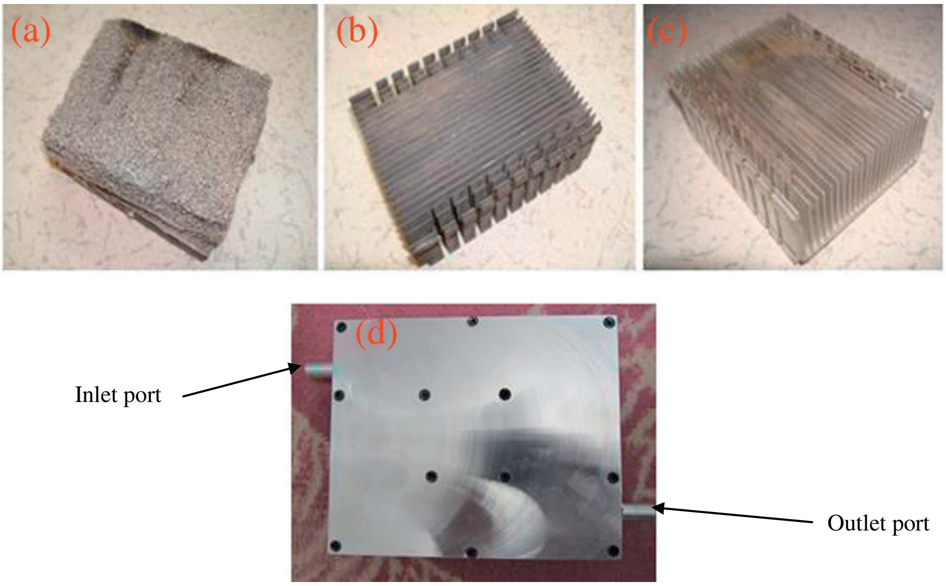


Fig. 1. (a) Metal foam, (b) coated, (c) uncoated, and (d) innovative heat sinks.

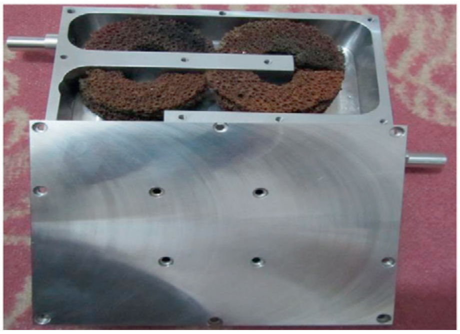
conducted an experiment combining a 4-mm diameter heat pipe and a heat sink, achieving a total thermal resistance of 0.29 °C/W.

Gernert et al. [26] studied an experiment on a heat sink with embedded heat pipes with a 25.4-mm diameter, 156 mm long heat pipe. For the maximum heat flux of 285 W/cm^2, it had the lowest total thermal resistance of 0.23 °C/W. Therefore, they concluded that the heat sink with embedded heat pipes was one of the best solutions for thermal problems in electronic components. Chiang [27] presented an effective method to predict and optimize the cooling performance of Parallel-Plain Fin (PPF) heat sink module. The design elements, including the outline design of the heat sink module, the wind capacity of the fan, and the highest temperature of this module were studied as the performance characteristics.

Hung and Yan [28,29] numerically examined the heat transfer enhancement of one-layered and double-layered microchannel heat sinks with nanofluids. They noticed that using an Al–water nanofluid has the greatest enhancement in microchannel cooling. Also, the thermal resistance of the heat sink could be the minimum by adjusting the

(a) Internal S-shape configuration

(b) Location of the metal foam(uncoated)



(c) Location of the metal foam(coated)

Fig. 2. Internal section of the innovative heat sink.