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Heat sink applications of extruded metal honeycombs

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Abstract

Linear Cellular Alloys (LCAs) are metal honeycombs that are extruded using powder metal-oxide precursors and chemical reactions to obtain near fully dense metallic cell walls. Either ordered periodic or graded cell structures can be formed. In this work, the performance of heat sinks fabricated from stochastic cellular metals is compared to that of LCA heat sinks. Flash diffusivity experiments are performed to determine the in situ thermal properties of cell wall material. The pressure drop for unidirectional fluid flow in the honeycomb channels and the total heat transfer rate of LCA heat sinks are experimentally measured. These measurements are compared to values predicted from a finite difference code and commercial computational fluid dynamics (CFD) software.

Keywords: Heat transfer; Cellular materials; Conductivity; Pressure drop

1. Introduction

Cellular metals are low density materials that combine certain stiffness, strength, crushing energy absorption and thermal characteristics, such as high surface area to volume ratios and high conductivity walls, in a way that makes them attractive for use in heat sinks. Cellular metals are composed of cells that can be categorized as (i) either open or closed foams and (ii) either stochastic or ordered. Regardless of the classification, cellular metals have a relative density given by ρ/ρ_s [1], where ρ is the density of the cellular metal and ρ_s is the density of the solid cell wall material. Various cellular material properties such as elastic stiffness, effective thermal conductivity, and effective yield strength can be directly related to the properties of the solid comprising the cell walls through the relative density [2]. Traditional polymeric and ceramic foams are known for their ability to insulate and inhibit the transfer of heat, e.g. polystyrene [1], quite distinct from heat exchange goals with cellular metals.

1.1. Stochastic cellular materials

Stochastic cellular metals can be made using several techniques [2], ranging from stirring foaming agents into molten metal to making an organic mold that is filled with molten metal or powder metal slurries and then the organics are burned out. The resulting cellular structure looks very much like cell structures in natural organic materials, as shown in Fig. 1.

When used as a heat sink, stochastic open-cell cellular metals are a porous medium through which coolant flows. High conductivity cell walls or edges facilitate heat flow from the source into the sink. A common heat

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Nomenclature

A_c	cross-sectional area
c_p	specific heat
D_h	hydraulic diameter
d	internal diameter of square cell
f	friction coefficient
g	gravitational constant
h_L	head loss
K	loss coefficient
k	thermal conductivity
L	heat sink length
L_α	thickness of diffusivity specimen
$\dot{m}$	mass flow rate
n	counter variable
P	pressure
P_w	wetted perimeter
ΔP	change in pressure from inlet to exit of heat sink
$\dot{Q}$	heat transfer rate
Re	Reynolds number
T	temperature
T^*	normalized temperature
ΔT	change in temperature
t	cell wall thickness
$\bar{v}$	mean velocity
z	height

Greek symbols

α	thermal diffusivity
γ	specific weight
μ	dynamic viscosity
ρ	density
T	time
ω	normalized diffusivity

Subscripts

E	expansion
f	fluid
I	inlet contraction
s	solid

sink arrangement for unidirectional flow is shown in Fig. 2.

In this configuration, heat is transferred via forced convection to the coolant, which flows in the positive z-direction in Fig. 2. Advantages of this porous structure include high surface area to volume ratio, as well as the enhancement of the heat transfer coefficient associated with turbulent patterns formed in the coolant [1]. The disadvantage of these stochastic porous structures is the large pressure drop in the fluid that requires increased pump power to drive the coolant flow [1,3]. This is primarily due to stagnation flow at the projections of the cell wall segments normal to the nominal flow velocity.

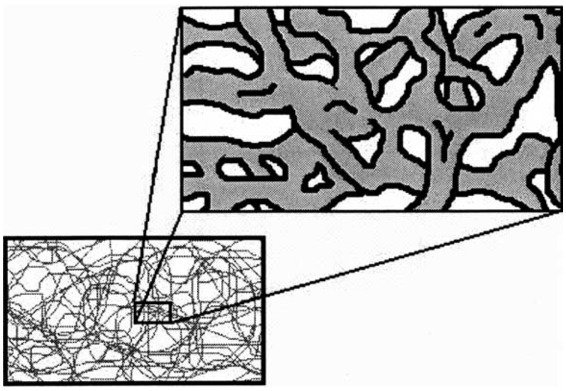

Fig. 1. Structure of stochastic open-cell cellular metal.

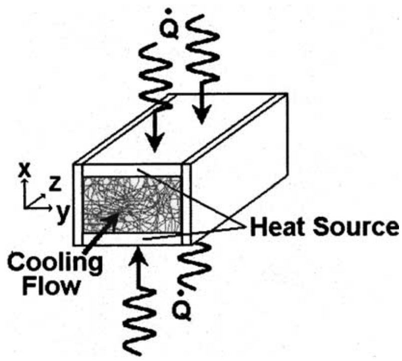

Fig. 2. Schematic of a stochastic cellular metal heat sink used to cool computer chips.

This setup was examined experimentally and numerically in Refs. [1,4]. Experiments were performed on aluminum cellular metal arranged in a manner similar to that shown in Fig. 2. The numerical simulations employed an approximation of the foam geometry as comprised of simple cubic unit cells consisting of banks of cylinders in various orientations.

1.2. Ordered cellular materials

Recent advances in low-cost manufacturing of ordered cellular metals have made it feasible to use these