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THERMAL FLOW THROUGH BRAZED WOVEN SCREENS

J. Tian*, T. J. Lu*, H. P. Hodson*, D. T. Queheillalt**, & H. N. G. Wadley**
**Cambridge University Engineering Department, Trumpington Street, Cambridge, CB2 1PZ, UK*
***Materials Science Department, University of Virginia, Charlottesville, VA 22903, USA*

Summary This paper presents experimental measurements and analytical predictions of pressure loss and heat transfer through brazed woven textiles under forced air convection. The main characteristics considered include porosity, solid thermal conductivity, and surface area density. The heat transfer performance of woven textiles is compared with other heat exchanger media including metal foams.

INTRODUCTION

High porosity, ultra-lightweight, cellular metal structures with open cell topologies have emerged in the past decade as attractive heat exchange media for a wide range of applications where dissipation of high intensity heat over relatively small spaces is demanded [1]. These cellular metal structures can be classified into two broad classes, one with a stochastic topology (e.g., metal foams) and the other with a periodic structure (e.g., brazed woven textiles, see figure 1). While stochastic cellular structures can be good compact heat exchangers, they are not as structurally efficient as their periodic counterparts. This arises because their deformation under mechanical loading is dominated by cell wall bending as opposed to cell wall stretching [2]. In this study, sandwich panels with woven textile cores are fabricated by using a transient liquid phase (TLP) bonding method to create robust nodes at wire crossovers and between the laminae. The overall pressure loss and heat transfer of the panels under forced air convection are measured and compared with those predicted using analytical models. Comparison with other heat exchange media is also made.

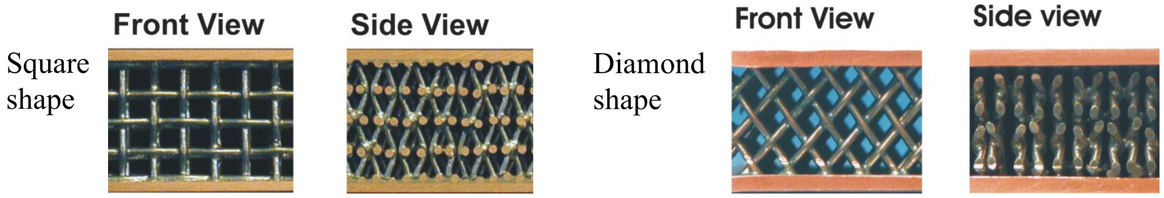

Figure 1. Two prototype textile laminate heat exchangers.

PRESSURE LOSS

Two pressure tappings placed separately in front of and after the test samples are used to obtain the pressure drop through woven screen structures. Samples with two different cellular configurations are measured: square shape and diamond shape (figure 1). The experimental results show that, at high Reynolds numbers, the pressure loss through woven screens is mainly caused by the pressure drag behind the wire ligaments. Friction factor based on channel height is independent of Reynolds number, indicating form-dominant flow in the range of Reynolds number considered. Different cellular configurations and different solid materials (copper and stainless steel are used in this study) are found to have negligible effect on pressure loss due to similar flow patterns. The main characteristic is porosity.

According to the analysis of pressure drag behind a wire ligament, the pressure loss through the structure is a function of open area ratio. Since the porosity and open area ratio are both functions of the ratio of wire diameter to aperture (*d/w*), the pressure loss depends mainly on porosity (or open area ratio). The analytical predictions agree closely with experimental measurements. The relationship between friction factor and open area ration is obtained as:

$$f = \frac{\Delta P}{1/2\rho V^2} \cdot \frac{H}{t} \sim \left(\frac{1 - R_{open}}{R_{open}} \right)^2 \cdot \frac{H}{t}$$

, where H is the channel height and t is the thickness of one layer ($t=2d$)

HEAT TRANSFER

Textile laminate heat exchangers with different porosities and different solid materials are studied. The overall heat transfer performance of these samples depends on the conduction through wire ligament, convection from the structure, and convection from the facesheets.

Experiment

The heat transfer performance of woven screens under steady-state forced air convection is obtained by measuring the inlet and outlet air temperatures and bottom wall temperatures. Nusselt numbers based on channel height are used. The results show that the heat dissipation capability of diamond shape samples are about 20%-30% higher than that of square shape samples having identical wire diameter and aperture. Copper samples have better heat transfer performance than stainless steel ones due to the higher solid thermal conductivity.

Analytical model

A fin analogy model is used to analyze the heat transfer performance of wire screens. Overall, the predictions compare favourably with those measured.

Discussion

Experimental and analytical results both reveal that the heat transfer performance of diamond shape samples is superior to square shape ones. Because of similar internal flow patterns, the main cause of this difference is due to conduction through wire ligaments. Even though the thermal conductivity of copper is about 20 times larger than that of stainless steel, the Nusselt number of copper textiles is only 3 times higher. At high porosity levels, the contribution of conduction through wire ligaments is less important than that contributed by convection from the cellular structures. At the same surface area density, it is found that a peak value of porosity exists for heat transfer. High porosity implies less solid material, and hence the contribution of conduction will be lower while the void volume will be bigger for convection. The different effects of porosity on conduction and convection lead to an optimum porosity (~ 0.8) for maximum heat transfer.

COMPARISON WITH OTHER HEAT EXCHANGE MEDIA

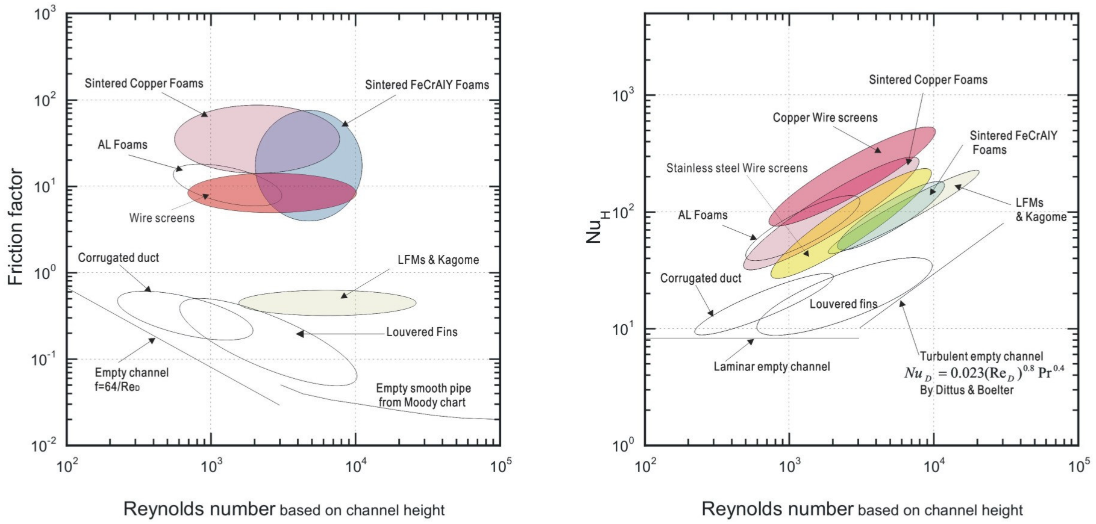

Figure 2. Thermal performance comparison of different heat exchange media.

Figure 2 compares the pressure loss and heat transfer performance of brazed wire screens with other heat exchange media including metal foams, LFMs (lattice frame materials) with tetrahedral unit cells [1], Kagome truss structures [2] and louvered fins. Notice that although the periodic woven structures typically have lower porosities than the stochastic metal foams, their friction factor is much smaller than those of metal foams. The fluid flow mechanisms of these two structures are different, which cause the difference in pressure loss. The heat transfer capability of copper wire screens appears to be superior to other media considered.

CONCLUSIONS

The overall heat transfer across woven textiles includes conduction and forced convection. Porosity and surface area density are two important characteristics at a given Reynolds number. Conduction and convection change in different ways with varying porosity. With increasing porosity, conduction decreases while convection increases. An optimal porosity for maximum heat transfer exists for a given surface area density. At a given porosity, the overall heat transfer increases as the surface area density is increased. Significant opportunities exist to maximize the heat transfer performance of periodic cellular metals by varying the pore fraction, anisotropy of the pores and metallic alloy used. Such manipulation can be accomplished by selection of the appropriate wire mesh.

References

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[2] A. G. Evans, J. W. Hutchinson, N. A. Fleck, M. F. Ashby and H. N. G. Wadley. The topological design of multifunctional cellular metals. *Progress in Materials Science*, 46:309-327, 2001.