# MICROVASCULAR HYBRID COMPOSITES FOR THERMAL ENERGY COLLECTION

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## 1 Abstract

We investigated the internal thermal transport properties of 8-ply, autoclave-cured, IM-7/977-2 carbon-fiber epoxy, quasi-isotropic laminates with metallic-lined microchannels as means for thermal energy collection. In cases where widespread incorporation of thermal harvesting devices is prohibited by cost, design or processing complexity; the overall amount and efficiency of thermal energy conversion may be enhanced with an embedded thermal energy collection system. For a single 103 ID /203 μm OD channel with a length of 15.2 cm, it was observed that ~1.4 and 2.7 W could be collected for a temperature difference of 26°C and 46 °C, respectively, between the outer surfaces in still air and the initial fluid temperature at the mid-plane.

Using a developed analytical thermal model and thermography, it was determined that the total internal thermal resistance was dominated by the composite “fin” resistance and that arrays of collection channels could significant enhance thermal energy harvesting as well as internally cool the panel.

## 2 Introduction

### 2.1 Composite Device Integration

Polymeric matrix composites are often preferred for integration of multifunctional systems due to their desirable mechanical properties and their ability to co-cure embedded elements. However, for structural thermal energy harvesting or storage systems, the low thermal conductivity of the polymer resin often necessitates consideration of internal thermal resistances in the design. While improvement of through-thickness thermal properties of laminated polymer composites continues to be addressed by researchers, additional means to transport thermal energy to an efficient conversion device may be needed [1,2]. It is envisioned that efficient light-weight, structurally-embedded thermal harvesting systems can be achieved with knowledgeable design of the structural, collection, and conversion components, in addition to improving device thermal conversion efficiency.

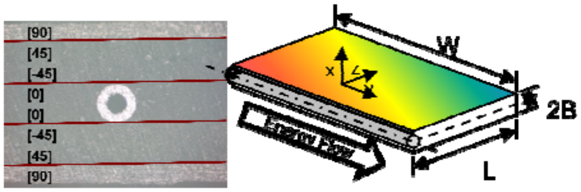

Fig.1. Cross section of fabricated panel with embedded thermal collection channels, panel dimensions and measurement coordinate system.

### 2.2 Thermal Energy Collection via Microvascular Channels

Embedded channels of different dimensions (100-400μm ID), were examined under different flow rates and with different initial temperature differences between the fluid and the panel surface. The fluid and panel surface temperature were monitored with thermocouples and surface thermography. An analytical expression for the thermal transport around the channel was developed to estimate the non-dimensionalized temperature (θ) of the panel from experimentally accessible values, boundary conditions, and the assumption that the thermal decay along the flow directions at the surface is the same as the fluid. The exponential decay constant along the channel is represented by β. Thus, the decay in temperature along the ydirection directly above the channel can be expressed as

$$\theta_f(y) = \exp(-\beta y). \qquad (1)$$

Using this expression and appropriate boundary conditions for thermal flow in the area perpendicular to the channel, the temperature can be expressed as

$$\theta_s(y,z) = \frac{A_0}{2}\cosh\left(\left(\frac{h_s}{Bk}\right)^{1/2}(L-z)\right) + \sum_{n=1}^{\infty} A_n \cos\left(\frac{n\pi y}{w}\right)\cosh\left(\left(\left(\frac{n\pi}{w}\right)^2 + \frac{h_s}{Bk}\right)^{1/2}(L-z)\right) \qquad (2)$$

with constants

$$A_n = \frac{2\beta\left((-1)^{n+1}\exp(-\beta w)+1\right)}{w\left(\beta^2 + \left(\frac{n\pi}{w}\right)^2\right)\cosh\left(\left(\left(\frac{n\pi}{w}\right)^2 + \left(\frac{h_s}{Bk}\right)\right)^{1/2} L\right)} \qquad (3)$$

where B,L,W are panel dimensions given in Figure 1 , $h_s$ is the surface heat exchange coefficient, and k in the thermal conductivity of the composite fin. Agreement between the analytical prediction and experimentally measured surface temperature was very high.

## 3 Results

### 3.1 Thermal Energy Collected

By measuring the temperature change between the inlet and outlet channel temperature and the flow rate, the amount of thermal energy exchanged can be measured as a function of fluid flow rate and values for the above variables can be calculated.

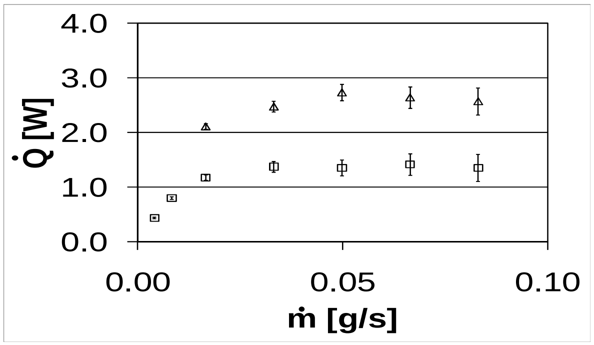

Fig.2. Thermal power exchanged between the fluid in a 15.2 cm long, 102 µm ID channel and the panel with $\Delta T_o$ at a 26°C (squares) and 46°C (triangles)

As indicated in Figure 2, the thermal power exchanged increases with increased fluid flow until it is saturated at a flow rate of approximately 0.5 g/s. This saturation is attributed to the inability the composite fin to exchange addition heat with the microchannel in the measured environment of still air.

### 3.2 Internal Thermal Resistance

By deriving expressions for the thermal resistance of the embedded channel and the composite fin, we can get additional confirmation that as the fluid flow rate increases the thermal resistance of the composite fin dominated the total resistance of the system.

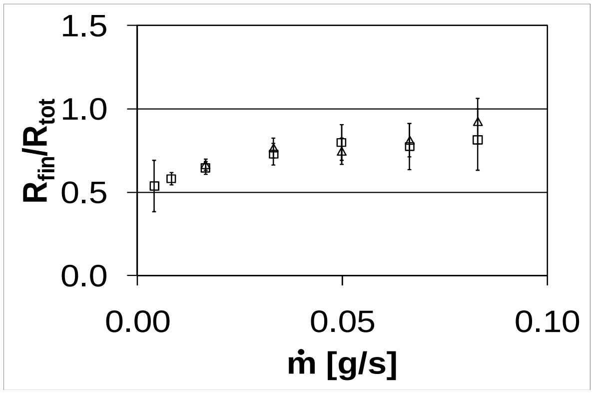

Fig.3. Relative thermal resistance of the composite fin in relation to the overall thermal resistance between the fluid and the environment.

## 4 Conclusions

A baseline analysis of an embedded thermal collection element was completed which may provide the foundation for future design of a thermal collection system which, when used in conjunction with a efficient thermal conversion device, could enable an efficient structural thermal energy harvesting system

## References

[1] K-M Wang, S. Lorente, A. Bejan "The transient response of vascular composites cooled with grids and radial channels". *Int. J. Heat Mass Transfer* Vol. 52, No. 19-20, pp. 4175-4183, 2009

[2] R.D. Kozola, L.A. Shipton, V.K. Natrajan, K.T. Christensen, S. R. White "Characterization of Active Cooling and Flow Distribution in Microvascular Polymers". *J. Intelligent Material Systems Structures*; Vol. **21, No.**12, pp 1147-1156, 2010.