3^{rd} International Conference on Self-Healing Materials
Bath, UK. 27-29 June 2011

COMPUTATIONAL DESIGN OF MICROVASCULAR MATERIALS

Alejandro M. Aragón[1] and Philippe H. Geubelle[2]

[1] University of Illinois, Department of Civil and Environmental Engineering,
205 North Mathews Avenue, Urbana, IL 61801, U.S.A.
Email: aaragon2@illinois.edu

[2] University of Illinois, Department of Aerospace Engineering,
104 South Wright Street, Urbana, IL 61801, U.S.A.
Email: geubelle@illinois.edu

Keywords: Microvascular materials, Active cooling, Multi-physics optimization, Multi-objective genetic algorithms

ABSTRACT

The focus of this study is the formulation, implementation and application of a computational framework to design microvascular materials, with special emphasis on active cooling applications. The computational design of these materials involves a set of particular challenges, including a large number of design variables (e.g., topology of the network, number of diameters to consider and their sizes) that define the embedded microvascular network, and a large number of multidisciplinary objective functions and constraints that drive the optimization process. The computational design tool to be developed must be capable of capturing the trade-off between the different objective and constraint functions, as, for example, networks designed for flow efficiency are likely to have a topology that is very different from those designed for structural integrity or thermal control.

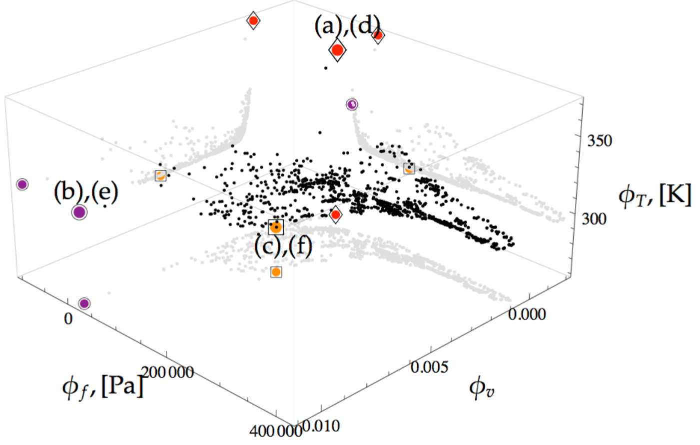

Figure 1: Pareto-optimal surface at generation t = 10000 for the periodic cell example. Individuals selected for visualization are displayed in Fig. 2 and are labeled in the front and marked with ◊, ◯, and □ symbols.

In this work, we propose to design these materials using Multi-Objective Genetic Algorithms (MOGAs). The result is a Pareto-optimal front, where all candidates are optimal solutions to the optimization problem. The MOGA optimization framework is also combined with a physical solver based on advanced finite element methods to study the thermal behavior of these materials. Because the MOGA requires a vast number of individual evaluations, emphasis is placed on the computational efficiency of the solver in both solid and fluid domains. Numerical experiments of multi-physics optimization involving flow efficiency, void volume fraction and thermal control are presented.

Results show that the trade-offs between conflicting objectives is well captured so that the optimal design is readily available to the analyst, as illustrated by Figs. 1 and 2.. Thus, a simplified formulation is used to take into account the cooling effect of the fluid, instead of solving the conjugate heat transfer problem for obtaining the temperature field

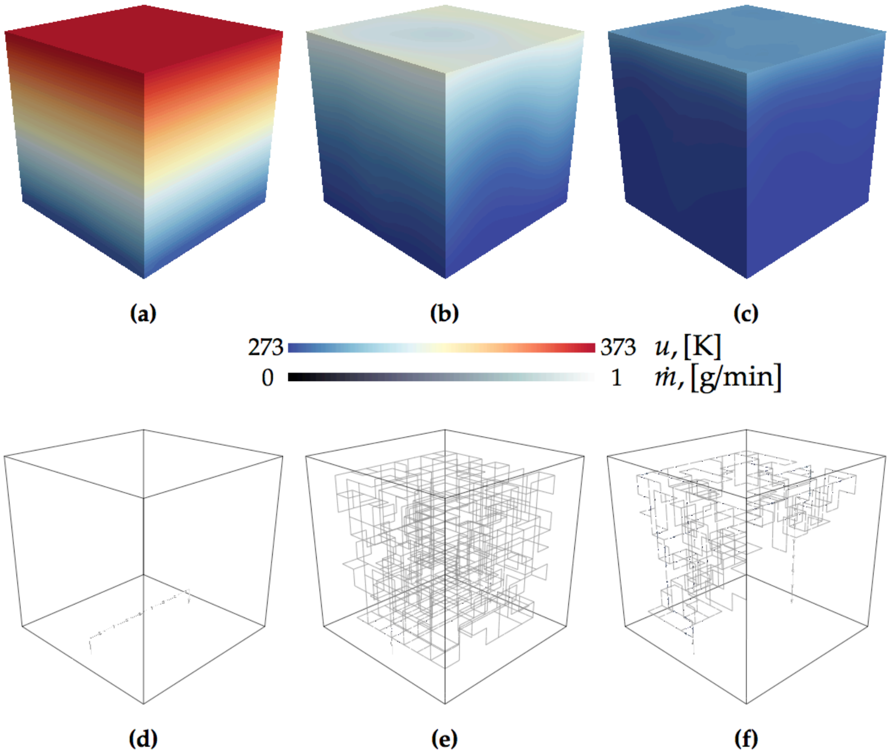

Figure 2: Selected candidate solutions at generation $t = 10000$ of the MOGA evolution. The upper row shows the temperature field, whereas the figures in the lower row show the corresponding flow field with their corresponding network. Figures (a) and (d) correspond to the individual that minimizes the void volume fraction, figures (b) and (e) to the individual that minimizes the pressure drop and figures (c) and (f) to the one that minimizes the maximum temperature. These candidate solutions are shown in the Pareto-optimal front of Fig. 1 with ◊, ◯, and ☐ symbols, respectively.

REFERENCES

[1] A. M. Aragón, J. K. Wayer, P. H. Geubelle, D. E. Goldberg and S. R. White, Design of microvascular flow networks using multi-objective genetic algorithms. *Computer Methods in Applied Mechanics and Engineering*, **197**, 2008, pp. 4399-4410, doi: 10.1016/j.cma.2008.05.025

[2] A. M. Aragón, C. A. Duarte and P. H. Geubelle, Generalized finite element enrichment functions for discontinuous gradient fields. *International Journal for Numerical Methods in Engineering*, **82:2**, 2009, pp. 242-268, doi: 10.1002/nme.2772

[3] A. M. Aragón, K. J. Smith, P. H. Geubelle and S. R. White, Multi-physics design of microvascular materials for active cooling applications. *Journal of Computational Physics,* Accepted for publication, doi: 10.1016/j.jcp.2011.03.012