CONDUCTIVE PATHWAYS CONSTRUCTION USING GENETIC ALGORITHM AND CONSTRUCTAL DESIGN

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ABSTRACT

In this work, Constructal Design and Genetic Algorithms are used to construct high conductivity paths connected to a heat sink and inserted in a square plate of low conductivity material with internal heat generation. The objective is propose a methodology that leads to minimize the maximum solid domain temperature. Total volume of the plate, amount of high thermal conductivity material and thermal ratio between high and low conductivities are fixed. The high conductive pathway forms found in this work greately resembles to the tree-forms found in nature, on which temperature is efficiently minimized by the application of the Genetic Algorithm and the Constructal Theory combined.

Keywords: constructal design; genetic algorithms; conductive pathways; heat transfer

NOMENCLATURE

A	plate area, m^2
D	height of heat sink, m
H	plate height, m
L	plate length, m
k	thermal conductivity, W m^{-1} K^{-1}
q_0	heat generation rate, W
c_p	specific heat, W $kg^{-1}K^{-1}$
T	temperature, K
x, *y*	spatial coordinates, m
W	plate thickness

Greek symbols

θ	dimensionless temperature
ϕ	relationship between material conductivities
β	relation between the area occupied by the high conductivity material and the area total

Subscripts

hs	heat skin
min	minimum
max	maximum
p	high conductivity
0	low conductivity

Superscripts

~	dimensionless variables

INTRODUCTION

With the decrease of the size of the electronic devices and the increase of this power, current problem of electronic devices cooling has been addressed with the construction of highly conductive pathways (Bejan, 2000a). Bejan (1997a) proposed a fundamental problem called Volume-to-Point (VP) in order to determine the optimal distribution of highly conductivity material within a finite volume with internal heat generation. Main goal to minimize the maximum temperature that occurs inside such devices. These problems have applications in a wide variety of sciences such as biology, economics and urban transport (Bejan, 1998; Bejan, 2000a; Bejan 2000b; Xu et al., 2007)

In this work, solution based on Genetic Algorithms (GA) and Constructal Design is proposed. The GA are based on natural evolution and operate with individual populations where those with better genetic characteristics are more likely to survive and reproduce, creating more fit individuals, and in which less fit individuals tend to disappear

(Goldberg, 1989, Linden, 2008). On the other hand, the Constructal Theory is understood as the tendency of all nature systems to evolve towards forms that provides easier access to the imposed currents that flow through it (Bejan, 1997b) and the Constructal Design is a strategy that emerged from seeing and apply the Constructal Theory in basic flow configurations and that can be applied in conjunction with various optimization methods to enunciate problems and explain or predict the flow structures of these (Bejan, 2000a; Bejan 2012).

Presented method combines natural evolutionary algorithm based on GA, with the Constructal Design, having as objective to construct high conductivity pathways inside a bimetallic plate, submitted to a heat source, in order to minimize the maximum domain temperature.

EXPERIMENTAL PROCEDURE

Figure 1 shows a two-dimensional solid plate submitted to a heat source and constructed with two types of materials, where H is the height and L is the length, D is the height of heat sink, and where k_p and k_0 represent the thermal conductivities, high and low, of the materials with which the plate is build. A steady conduction heat transfer problem is solved by finite volume method. The surfaces of the plate are perfectly insulated with the exception of the region where the heat sink is located. At this location, constant variable condition (T_{hs}) is prescribed

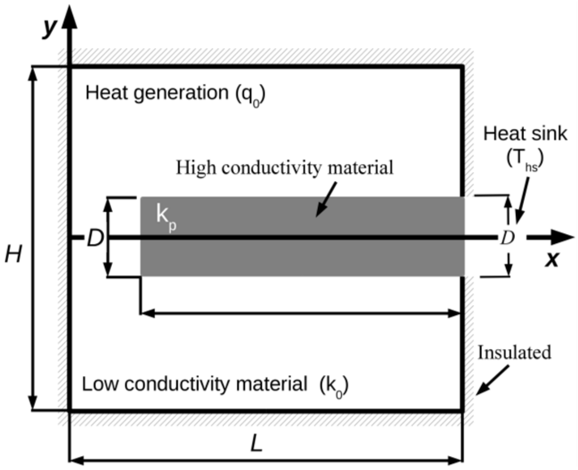

Figure 1. Problem description.

The amount of high conductivity material available for the construction of the plate depends on the high and low conductivity area ration

$$\phi = \frac{A_p}{A} \quad (1)$$

and on the ratio between materials conductivities given by

$$\beta = \frac{K_p}{K_0} \quad (2)$$

Heat transfer problem is govern by

$$k_0 = \frac{\partial^2 T}{\partial x^2} + k_0 \frac{\partial^2 T}{\partial y^2} + \frac{q_0}{\left(A - A_p\right)W} = 0 \quad (3)$$

for the region with low thermal conductivity material, and

$$k_p = \frac{\partial^2 T}{\partial x^2} + k_p \frac{\partial^2 T}{\partial y^2} = 0 \quad (4)$$

for the region with high thermal conductivity material. In Eqs. (1) to (4) $T$is the temperature [K], x and y are Cartesian coordinates [m], q_0 is the heat generation rate [W] and W is the thickness of the board (equal to 1) [m].

The dimensionless thermal resistance is defined by:

$$\theta_{\max} = \frac{\left(T_{\max} - T_{hs}\right)W}{q_0 / k_0} \quad (3)$$

Proposed methodology for the construction of high conductivity pathways combines Genetic Algorithms and the constraints defined by the Constructal Design theory. Application of the methodology is done in steps. In the first step of the proposed methodology, begin by defined the objective function, mesh size, constraints and the genetic algorithm parameters. In the following steps, GA is applied to search for the best positions for the material available. This is done following the own steps for the application of an evolutionary algorithm that begins with the generation of the initial population, in this case, in a random way, being each element of the mesh with high conductivity, an individual of the population. Within the same application of GA, the validation of each individual is made from its temperature, which is obtained after the solution of the temperature field. Then proceed to apply the genetic operators of crossing and mutation for the creation of a new individual generation and finally the new population which corresponds to a new solution to the problem. This is done during a fixed number of iterations (generations of GA) and the temperature field is calculated immediately after each GA solution. Everything is done starting from a random distribution for the high conductivity material. Each application (generation) of the GA offers a solution for the problem. This solution is changed and improved with the progress of the iterations, until a final location for the material is determined.

RESULTS

Some results obtained after implementing and applying the proposed methodology are presented in Fig. 2. These correspond to a plate of area $A=1$, uniform heat generation q_0, $D=0.1$, and 10000 elements. Main goal is to minimize θ_{max}.

Figure 2 also exemplifies the process of constructing the high conductivity pathway for a plate with $\phi=0.09$ and $\beta=5$ over *100* iterations (GA generations) and a final distribution of the material with high thermal conductivity material (black elements) available forming the high conductive pathway connected to the heat sink. In the image, can be see how the material tends accumulates always near the location of the heat sink.

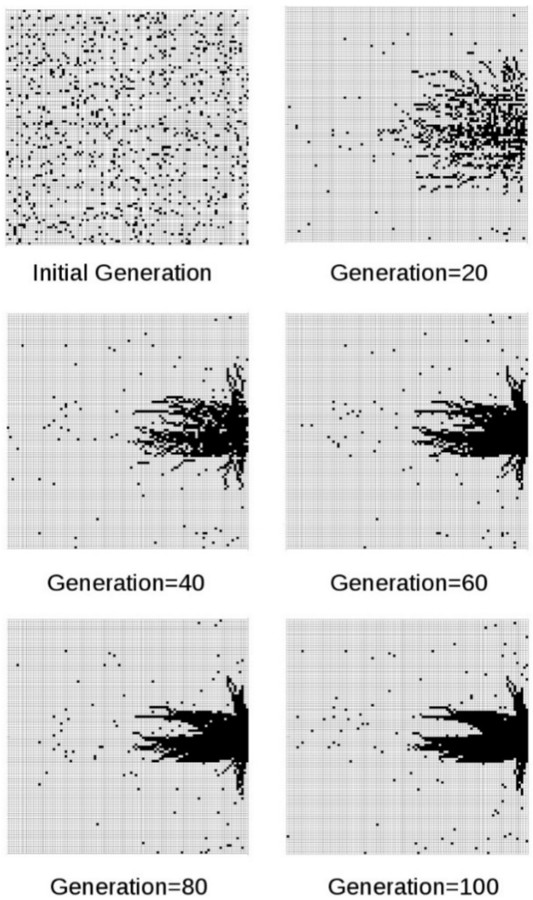

Figure 2. Construction conductivity pathway with $\phi=0.09$ and $\beta=5$.

Starting with a random distribution of the material, leads to find different solutions for the same plate each time the methodology is applied. For the previous plate with $\phi=0.09$ and $\beta=5$, four simulations were performed and the results of the different configurations obtained for the high conductivity material, as well as θ_{max} value obtained in each case, were compared and are shown in Fig. 3.

θ_{max} obtained for the four configurations is always close with a standard deviation of $7.37\text{x}10^{-4}$, and the comparison can be seen in Fig. 4. In addition, in all cases, the decrease in temperature throughout the iterations (generations) was considerable, decreasing the thermal resistance between 76.05% and 84.5% with respect to the random arrangement of the material., and this can be seen in Fig. 5.

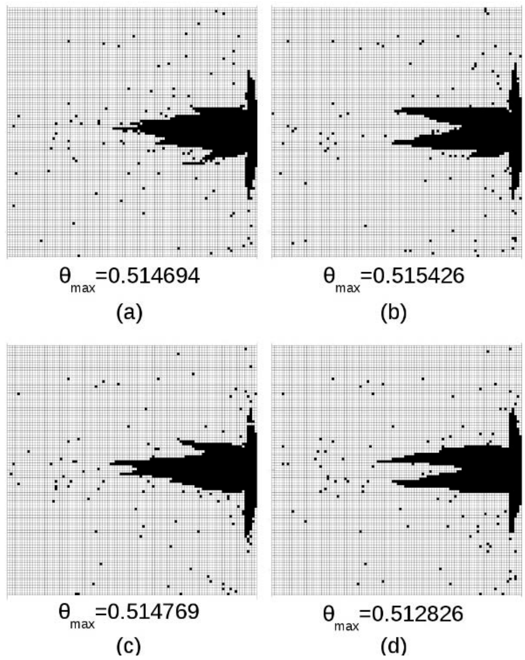

Figure 3. Configurations obtained for the four simulations of the case with $\phi=0.09$ and $\beta=5$.

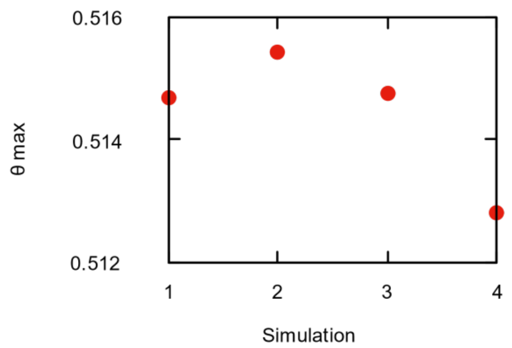

Figure 4. Comparison results obtained in Fig. 3.

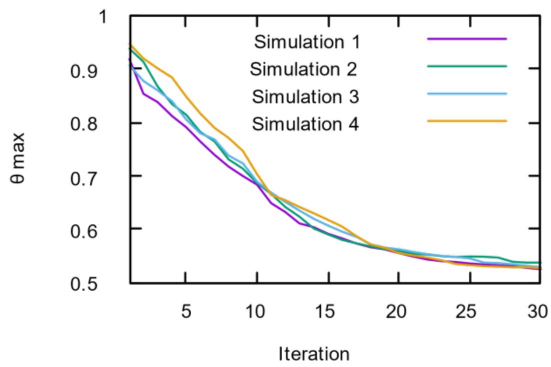

Figure 5. θ_{max} behavior for the cases presented in Fig. 3.

Taking into account the above, four simulations are performed for plates with $\phi=0.09$ varying the ratio between materials conductivitie, with $\beta=10.30$ and *300*, and the results obtained are presented in Tab. 1. The solution that presented a less dimensionless thermal resistance is mark.

Table 1. θ_{max} obtained for plates with $\phi=0.09$ and $\beta=10.30$ and *300* for four different simulations.

Beta	Sim. 1	Sim. 2	Sim. 3	Sim. 4
10	0.37958	0.386327	0.381711	0.383237
100	0.164372	0.1784	0.150533	0.155908
300	0.157751	0.115862	0.133696	0.132184

Figure 6 shows the configuration of the conductive pathway as well as the field temperature of the best results obtained for plates with $\phi=0.09$ and $\beta=10.30$ and *300*.

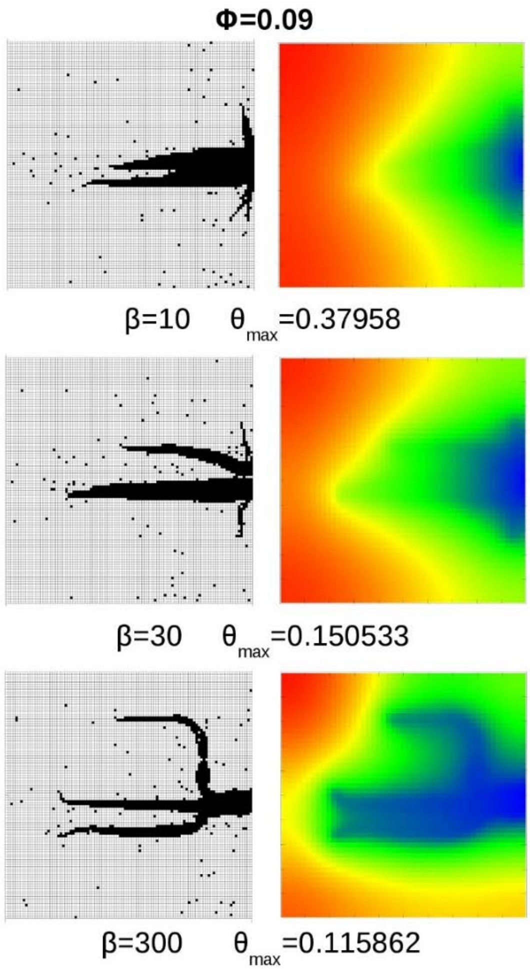

Figure. 6. Best results amount simulated for different plates with $\phi=0.09$ and $\beta=10.30$ and *300*.

The value of decreased with the progress of the iterations and the performance of the system after applying the proposed methodology improved for the three cases in 139.76%, 253.4% and 597.1% respectively with respect to the random arrangement of the material. The standard deviation between the four simulations for each variation of $\beta=10.30$ and *300*. Prove to be 2.84×10^{-3}, 1.21×10^{-2} and 1.73×10^{-2} respectively.

CONCLUSIONS

This work proposed a methodology to minimize the global thermal resistance into a solid domain.The purpose of cooling the volume through conductive pathways, constructed using the Genetic Algorithm technique in association with Constructal Design, was achieved. The θ_{max} decreased with the addition of material and the evolutions of the GA until arriving at an almost optimal solution. The decrease of the maximum non-dimensionaless temperature for the simulated cases was between 76.05% and 84.5%. It was found that with the proposed methodology, for the same problem different solutions can be found, however, the standard deviation between these solutions was always no greater than 1.21×10^{-2}. The use of GA was very useful since their use minimized the computational effort required by other approaches. In addition to the above, the geometries of the highly conductive paths had a great similarity with the trees that are found in nature.

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