Optimal Transmission Conditions for Thin Adhesive Layer Based on Colonial Competitive Algorithm

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Abstract

In this paper a novel evolutionary global search strategy called Colonial Competitive Algorithm (CCA) is utilized to determine an optimal imperfect transmission condition for a thin intermediate layer between two bonded materials in a dissimilar strip with a temperature-dependent source or sink formulation. The recently introduced CCA has proven its excellent capabilities such as faster convergence and better global optimum achievement. When finally compared with finite element analysis, the CCA shows excellent prospect in the design of adhesive joints.

Keywords: Colonial competitive algorithm (CCA), Adhesive Layer, finite element analysis, Transmission condition.

1. INTRODUCTION

Adhesive joints have found applications in many areas such as aerospace, aeronautics, electronics, constructions, sports and packaging [1]. Various imperfect transmission conditions for thin reactive heat-conducting adhesive layers were investigated by [2, 3, 4, 5, 6, 7].

Global optimization is an inherent problem in science and engineering. Many evolutionary algorithms [8, 9] have been proposed for solving the global optimization problems.

Colonial competitive algorithm is a new optimization algorithm that was recently introduced for solving various optimization problems. CCA is a universal search strategy that uses the sociopolitical competition among empires as a source of development inspiration [10]. CCA has been applied successfully in different domains, namely, design of controllers [11-12], recommender systems, characterization of elasto-plastic properties of materials [13] and many other optimization problems [14-15]. When compared to other optimization approaches, the results have shown good performance in both convergence rate and better global optima achievement.

The purpose of this paper is to obtain optimization of transmission conditions for a reactive thin adhesive layer in a hybrid model structure (see Fig. 1) by using the CCA. In this study the transmission condition is linear from the source to the intermediate layer.

2. PROBLEM FORMULATION

Consider a plane problem domain with a thin adhesive layer between two different materials (Fig. 1).

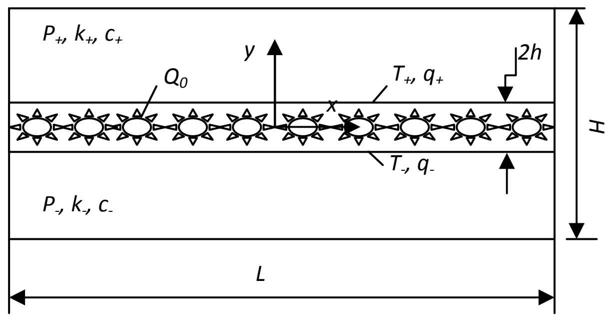

FIGURE 1: Specimen problem for heat conduction

The function ψ can be expressed as:

$$\psi(q_-,T)=\int_{T_-}^{T}\frac{dz}{\sqrt{1-\phi(z)/q_-^2}} \tag{1}$$

Where ϕ is introduced as:

$$\phi(T)=2k\int_{T_-}^{T}Q(z)dz \tag{2}$$

The above relation can be written in the intermediate layer in equivalent forms by adding and subtracting each other as:

$$k\psi(q_-,T_+)-2k\psi(q_-,T)=2q_-.h \tag{3}$$

Where q is the y-component of heat flux and T is temperature and Q is the heat source of the specimen which exhibits temperature-dependent source and sink. The form of the source is:

$$Q=Q_0.T \tag{4}$$

This problem refers to a steady-state solution where boundary conditions material properties are chosen. As shown in a previous paper [7] in the case of a linear temperature dependency, the first transmission condition (1st TC) can be obtained as:

$$q_+^2(x,+h)-q_-^2(x,-h)=-kQ_0(T_+^2(x,+h)-T_-^2(x,-h) \tag{5}$$

The second transmission condition (2nd TC) has also been shown for the case of source $(Q_0>0)$ as:

$$\arcsin\frac{T_+\sqrt{kQ_0}}{\sqrt{q_+^2+kQ_0T_+^2}}-\arcsin\frac{T_-\sqrt{kQ_0}}{\sqrt{q_-^2+kQ_0T_-^2}}=-2h\sqrt{\frac{Q_0}{k}}.sign(q_-) \tag{6}$$

The second transmission condition for the cases $Q_0>0$ can be rewritten in the following as

$$\arcsin\frac{T_+\sqrt{kQ_0}}{\sqrt{q_-^2+kQ_0T_-^2}}-\arcsin\frac{T_-\sqrt{kQ_0}}{\sqrt{q_-^2+kQ_0T_-^2}}=\pi+2h\sqrt{\frac{Q_0}{k}}.sign(q_-) \tag{7}$$

The second transmission condition of Eq. (1), in the case $Q_0 < 0$, can be written in the following form:

$$\psi(q_-, T) = \frac{|q_-|}{\sqrt{-kQ_0}} \log\left| \frac{T\sqrt{-kQ_0} + \sqrt{(T_-^2 - T^2)kQ_0 + q_-^2}}{T_-\sqrt{-kQ_0} + |q_-|} \right|. \quad (8)$$

Then, second transmission condition of Eq. (7) can be written in the form:

$$\ln \frac{\left(|q_+| + T_+\sqrt{-kQ_0}\right)\left(|q_-| + T_-\sqrt{-kQ_0}\right)}{\left|kQ_0T_-^2 + q_-^2\right|} = 2h\sqrt{\frac{-Q_0}{k}}\,\mathrm{sgn}(q_-), \quad (9)$$

3. FINITE ELEMENT MODELING

In this section stepping the FEM is engaged to validate the optimization results. The commercial finite element code MSC-Marc is used for the simulation of thermal behavior a thin interphase layer located between two adherents. Both adherents use constant material properties for all simulations; these are constant conductivity $k_\pm = 237$ w/(m.k) at 300°K, mass density $\rho_\pm = 2598.8$ kg/m^3 and specific heat $c_\pm = 898.2$ J/(kg.K°). The thin interphase layer is assumed to be made of an epoxy resin ($\tilde{k} = 0.2$ w/(m.k), $\rho = 1200$ kg/m^3, $c = 790$ J/(kg.K°)) and exhibits different values of the linear temperature dependence of the source. In the simulations, the interphase layer has thickness $2h = h/100 = 0.01$ m and $L = 10$ m.

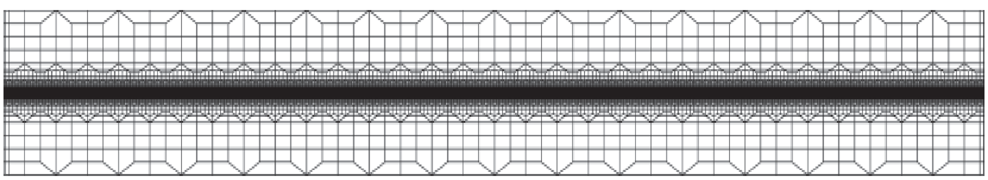

FIGURE 2: Two-dimensional finite element mesh

The 2D finite element mesh is built up of four-node (see fig. 2), isoperimetric elements with bilinear interpolation functions. The source or sink formulation is implemented by means of a special user subroutine written in FORTRAN. The application of this program requires a transient solution in order to incorporate the source expression.

4. COLONIAL COMPETITIVE ALGORITHM

Colonial competitive algorithm (CCA) is a new evolutionary optimization method which is inspired by the imperialistic competition algorithm. Like other evolutionary algorithms, it starts with an initial population, called country, which consists of colonies and imperialists. The imperialistic competition among these empires forms the proposed evolutionary algorithm. Imperialistic competition converges to a state in which there exists only one empire and colony have the same cost function value as the imperialist.

The total power of empires depends on both the power of the imperialist country and the power of its colonies which is:

$$C.C_n = \textit{cost function}\ (\textit{imperialist}_n) + \zeta\ \textit{mean}\ \{\textit{cost}\ (\textit{colonies of empires}_n)\} \quad (10)$$

This competition gradually brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones. This is modeled by just picking some of the weakest colonies of the weakest empires and making a competition among all empires to possess these colonies. Figure 3 is a flowchart of the colonial competitive algorithm (CCA).

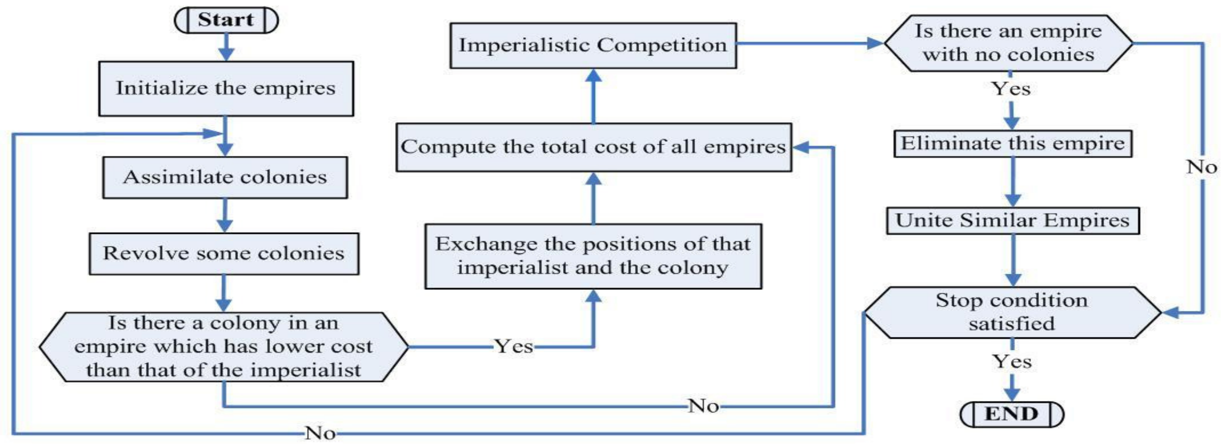

FIGURE3: Illustration of imperialist of competitive algorithm (CCA)

In application the CCA has been used in designing PID controller [16], achieving Nash equilibrium point [17], characterizing materials properties, beam forming, design of vehicle fuzzy controller, and others.
In this paper, this algorithm is applied for optimizing the imperfect transmission conditions for thin interphases.

To obtain optimal design, considering both source factor and efficiency, the objective function is defined as follows [12].

$$J_{\tau} = (x_1,...,x_n) = \eta(x_1,...,x_n)^{\lambda_1}.\phi(x_1,...,x_n)^{\lambda_2} \quad (11)$$

Where λ_1, λ_2 are constant and $x_1,...,x_n$ are design variables. When efficiency is more important than power factor, $\lambda_1 = 1$, $\lambda_2 = 0$ are selected. When source factor is more important $\lambda_1 = 0$, $\lambda_2 = 1$ are selected. By considering $\lambda_1 = \lambda_2 = 1$ both efficiency and source factor will be optimize simultaneously.

In this optimization problem the goal function is the inverse of Equation (11). The optimization variables are the upper and lower components of heat flux on the interface (q_+, q_-) and the upper and lower temperatures on the interface (T_+, T_-).

5. RESULTS AND DISCUSSION

All numerical simulations are carried out for the similar aluminum adherents and epoxy resin interphase layer. The boundary conditions are taken as a uniform temperature at the top (180°K to 540°K at *y* = +*H*/2) and the bottom surface (145°K to 435°K at *y* = -*H*/2). The source exhibits linear temperature dependence (see Fig. 1). Figures 4 and 5 are shown the temperature and heat flux distributions at the interface, i.e. *y* = ±*h*, along the *x*-line obtained by finite element analysis for the case of linear positive and negative heat sources.

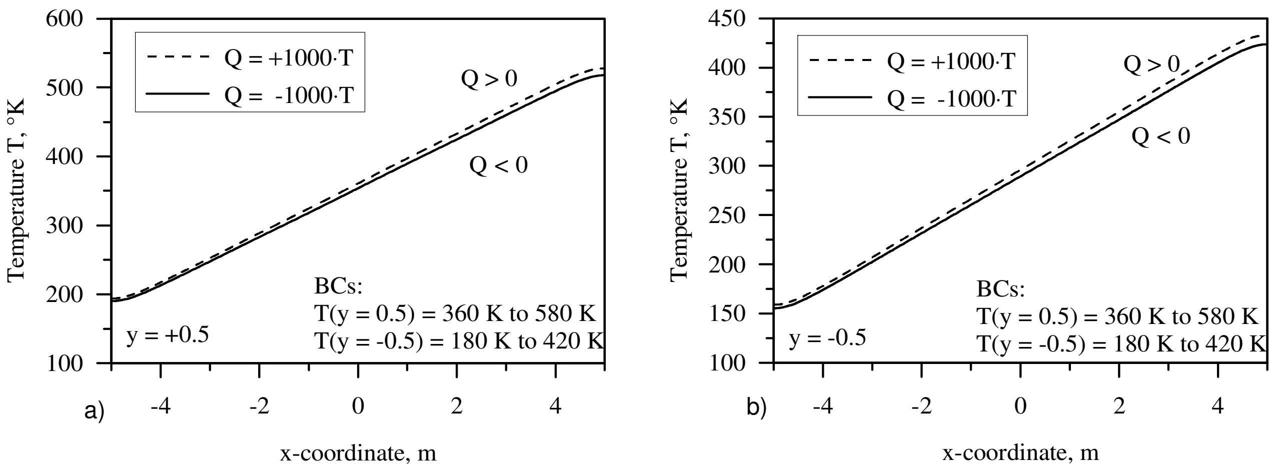

FIGURE 4: Temperature distribution on a) the upper interface b) the lower interface in a linear source - FEM

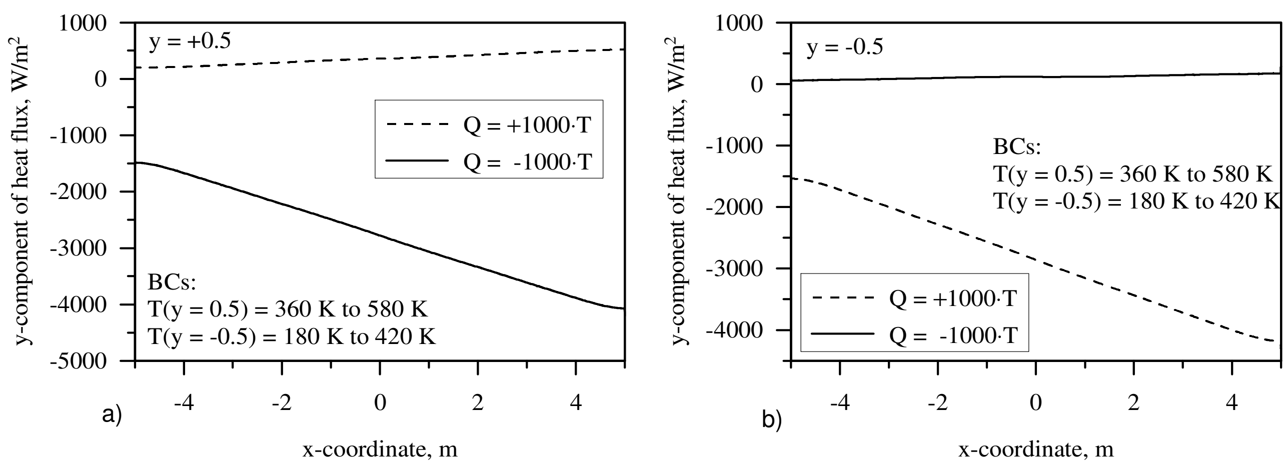

FIGURE 5: Distribution of *y*-components of heat flux on a) the upper interface b) the lower interface in a linear source -FEM

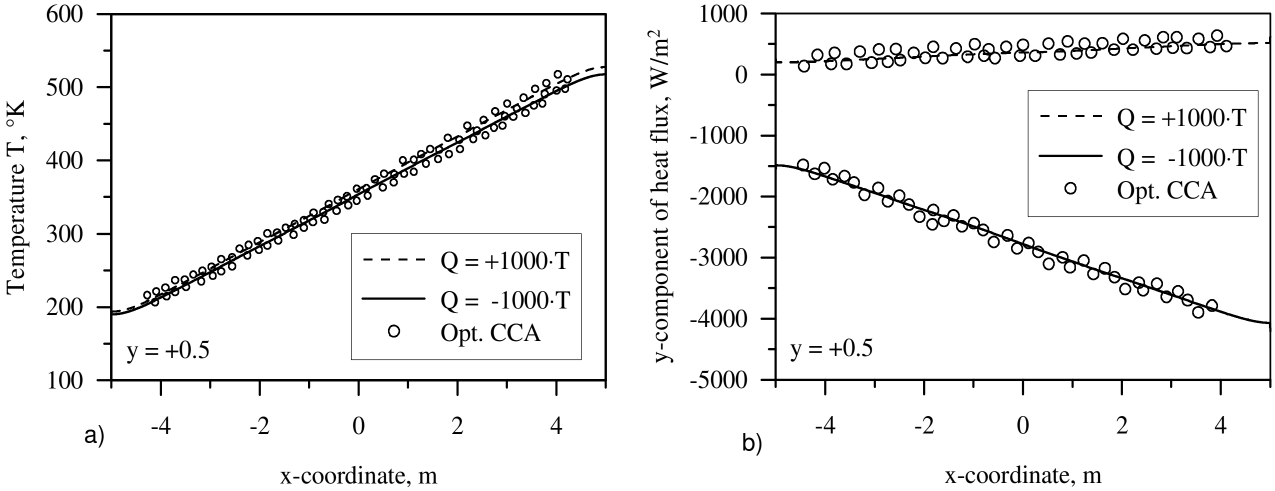

FIGURE 6: Optimizations results with CCA at a) the upper temperature, b) the upper y-component of heat flux on the intermediate layer

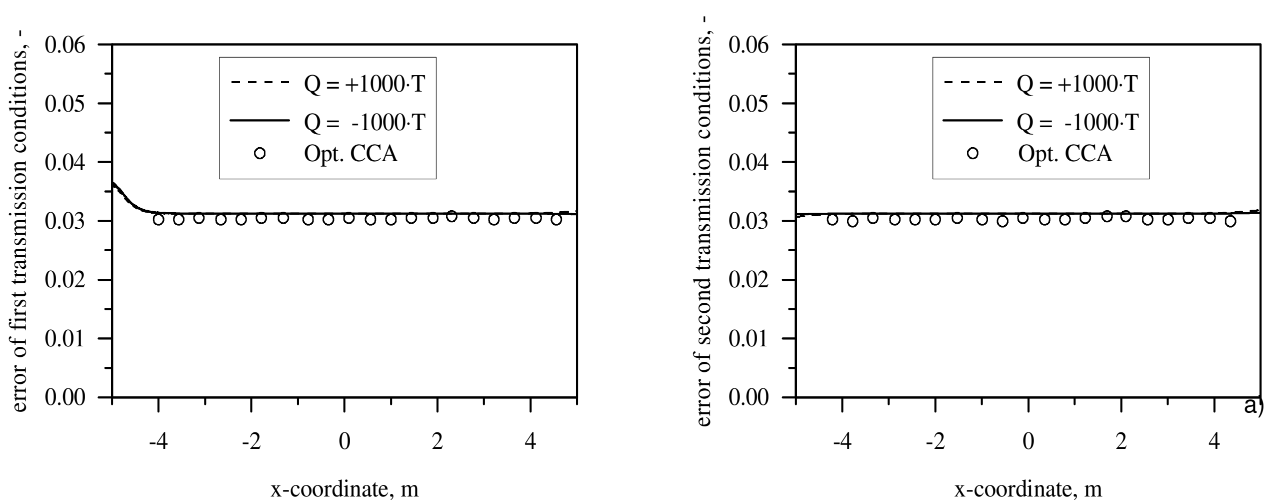

FIGURE 7: Transmission errors with CCA for a) error of first transmission condition, b) error of second transmission condition in a linear source

The optimal values of the temperature and the heat flux along the *x*-line at the upper interface are evaluated. They are illustrated by circle markers in Fig. 6. In Figure 7, the solid lines represent the verification of transmission conditions (1^{st} and 2^{nd} TC) by independently extracting the right (RHS) and left hand side (LHS) of Equations (5, 7 and 9) from FEM evaluation. The value of the error of transmission condition was obtained by calculating the difference of the LHS and RHS and relating this difference to the RHS of the respective transmission condition. When optimization was implemented using colonial competitive algorithm (CCA) the value of the error of transmission condition is reduced and depicted by circle markers in Fig. 7.

When compared with finite element method, it can be seen that the colonial competitive algorithm (CCA) has improved the accuracy of transmission condition in the thin adhesive layers for heat-conduction problems.

6. CONCLUSION

It has been shown in this work that the new optimization based on colonial competitive algorithm (CCA) is able to reproduce the same results at the classical approach which is based on the finite element method. The comparison shows that the excellent prediction by CCA makes it a viable tool for optimizing heat-conducting problems on adhesive layers. Future works would include analysis and simulation of thin reactive interphase layers and optimization it based on genetic algorithm and colonial competitive algorithm.

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