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A METHODOLOGY TO ESTIMATE THERMAL CONDUCTIVITY USING INVERSE METHOD

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ABSTRACT

This paper reports a methodology to estimate the principal thermal conductivities (kx and ky) of an orthotropic composite material by using inverse heat transfer. In the study a two dimensional steady state heat conduction equation with heat generation for an orthotropic material has been investigated. A grid independent study has been carried out using ANSYS for fine mesh size and its obtained as 120x120.With this mesh size of 120x120 by varying the thermal conductivities the temperature distribution of the orthotropic composite material at different location are calculated and these values are used for inverse heat transfer analysis using Artificial neural network(ANN).

NOMENCLATURE

kx	Thermal conductivity of sample along x direction, W/m K
ky	Thermal conductivity of sample along y direction, W/m K
ANN	Artificial Neural Network
T	Computed temperatures,^{0}C
q	Heat generation per unit volume, W/m^3
x, y	Cartesian coordinates

1. INTRODUCTION

Composite materials composed of two or more macro constituents with differ in form or material composition and insoluble in each other. Composite materials are extensive used in engineering for their well-known thermal properties. Knowledge of thermal conductivity of composite materials play an important role in thermal designing.

An experimental procedure for the simultaneous estimation of the thermal conductivity tensor and specific heat of orthotropic composite materials has been developed by Thomas et al. [1], which uses an ordinary least square method for inverse methodology. Chanda et al. [2] experimentally estimated the thermal conductivities of an anisotropic composite medium using inverse heat transfer. Deng and Hwang [3] applied neural network (ANN) to compute the temperature distribution in forward heat conduction problems and solved inverse heat conduction problems by using a back propagation neural (BPN) network to identify the unknown boundary conditions. Mara et al. [4] proposed a numerical algorithm based on a classical boundary element method (BEM) combined with the least squares technique to simultaneously predict the unknown conductivity coefficients and boundary data for a steady state heat conduction problem in an anisotropic medium. Dong et al. [5] extended the inherently mesh less and integration-free method to solve two-dimensional inverse heat conduction in an anisotropic medium.

The preceding literature review discusses various methods for the estimation of thermal conductivity of a material. Even so, inverse heat conduction problem using ANN is scarce. The objective of present study is to propose a methodology to estimate the thermal conductivity of composite material using ANN.

2.METHODOLOGY

In the study a two dimensional steady state heat conduction equation with heat generation for an orthotropic material has been investigated.

The heat conduction equation of the orthotropic composite material is given by

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial T}{\partial y}\right)+q=0 \qquad (1)$$

Where T=temperature

q= Heat generation per unit volume

kx = Thermal conductivity of the composite material along x-direction

ky = Thermal conductivity of the composite material along y-direction

The problem considered here is a square slab of side 1m with type-1 (Dirichlet) boundary condition on all the edges. A low thermal conductivity orthotropic material is used for the investment and in the range of 1-5W/m K having a uniform heat generation of 1000 W/m^3.

The schematic diagram of the experimental set up is shown in Fig-1. The experimental setup consist of a square slab having the dimension 1m and the boundary conditions are

1) Temperature at left boundary= 75^{0}C
2) Temperature of the bottom boundary = 0^{0}C
3) Temperature of the right boundary = 50^{0}C
4) Temperature of the top boundary = 100^{0}C
5) Uniform heat generation rate = 1000 W/m^3
6) Thermal conductivity of the material kx and ky vary from 1-5 W/mK.

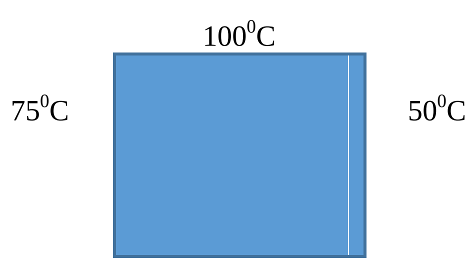

Fig-1 SCHEMATIC DIAGRAM OF THEPROBLEM

A grid independent study has been carried out by using ANSYS Mechanical APDL and fine mesh size found as 120x120.The grid independent study of the material at kx=2 W/mK, ky= 3 W/mK and q= 1000W/m^3 is listed in Table-1.

TABLE-1 GRID GENERATION DATA

Coordinates		Temperatures							
x	Y	10x10	20x20	40x40	60x60	80x80	100x100	120x120	240x240
0.4	0.4	75.2795	74.9358	74.8517	74.8362	74.8307	74.8282	74.8269	74.8259
Error in (%)		0.456	0.112	0.0207	0.00735	0.00334	0.00174	0.00137	

Artificial neural network

An artificial neural network (ANN), usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural network. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation.

The objective of the neural network is to transform the inputs into meaningful outputs.The inverse problem is used for the estimation of kx and ky for the given measured temperature distribution. In the present study ANN is used for the parameter estimation process. ANNs are used to correlate a set of inputs with a set of outputs, thus enabling them to predict outputs for new sets of inputs, within a particular range. A neural network consists of one input layer, one output layer, and one or more hidden layers accompanied by a number of neurons which are interconnected with each other using synapses or connections (ref.Chanda et.al [2]).

By varying the thermal conductivities the temperature distributions at specified locations of the problem is solved by ANSYS.With these data a neural network is formed for 5 hidden neurons. The temperature distribution corresponding to kx=2.3 W/mK, ky=3.7 W/mK and q=1000 W/m^3 tabulated with ANSYS.Fig-2 shows the schematic diagram of ANN .Fig-3 shows the schematic diagram of the entire methodology showing how the ANSYS model, ANN and the estimation of thermal conductivity are related.

From the grid independent study the percentage error of temperature between mesh size 120x120 and 240x240 is 0.00137 hence the fine mesh size is fixed as 120x120.With this fine mesh size by varying the thermal conductivity of the orthotropic material along x and y direction a set of temperatures of the material at specified locations are obtained by using ANSYS and these values are used for ANN.

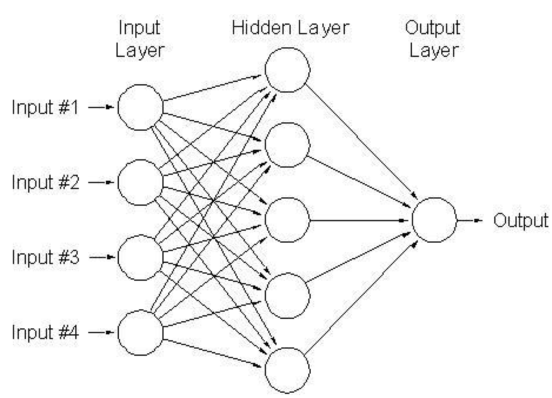

Fig-2 SCHEMATIC DIAGRAM OF ANN

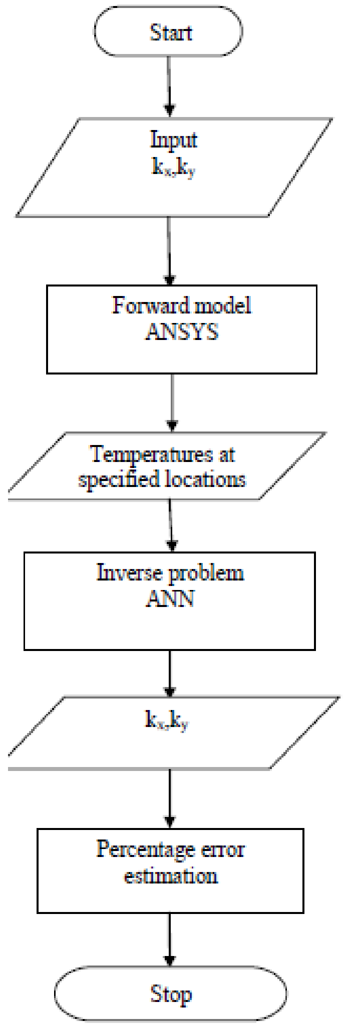

Fig-3 SCHEMATIC DIAGRAM OF THE

3. RESULT AND DISCUSSION

This present work proposed a methodology to estimate the thermal conductivity of the composite material using inverse heat transfer analysis. In the study a two dimensional steady state heat conduction equation with heat generation for an orthotropic material has been investigated. A grid independent study has been carried out using ANSYS for fine mesh size calculation and its obtained as 120x120.With this mesh size by varying the thermal conductivities, the temperature distribution of the orthotropic composite material at specified location are calculated and these values are used for inverse heat transfer analysis using ANN. The direct problem is solved by ANSYS software and the inverse problem is solved by ANN.

Temperatures at specified locations are obtained using the forward model. The forward model is developed by varying the thermal conductivity between 1-5 W/mK keeping the heat generation constant of 1000W/m^3. A neural network is trained using 50 samples of temperature data obtained at specified locations in the sample obtained using the forward model. After training, testing and validating the ANN network is used as the inverse tool to obtain the thermal conductivity for a give temperature distribution. Real experiments can be conducted with the given boundary condition and heat generation rate for an unknown thermal conductivity in the prescribed range. The temperature distribution thus obtained can be used as the input to the ANN. In this study to demonstrate the methodology we have developed temperature distribution using again the forward model ANSYS, and the deviation in the output of ANN was found to be 0.3 and - 0.1784 % respectively.

4. CONCLUSION

A methodology to estimate the thermal conductivity of the composite square slab has been carried out. The direct problem is analysed using ANSYS and a neural network is developed to estimate the thermal conductivity. Corresponding to a given value of kx and ky the temperature distribution is calculated using ANSYS (which can also be replaced by experiments) and the temperature datas thus obtained are used as input to the neural network. The output of the ANN was found to have percentage variation of 0.3 and - 0.1784 respectively in kx and ky.

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