Evolutionary computation in identification of thermophysical properties of hardening concrete

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Abstract

The evolutionary computation procedures in identification of thermophysical properties in hardening massive concrete structure are presented. Heat of cement hydration, thermal conductivity and specific heat are determined for purpose of modelling temperature evolution in massive concrete elements. The knowledge about temperature fields is very important due to linked with them undesired thermal stresses, which can cause a weakening of the structure because of thermal cracking. The proposed method is based on point temperature measurements in a cylindrical mould and the numerical solution of the inverse heat transfer problem by means of finite element method and evolutionary computation.

Keywords: thermophysical properties of concrete, inverse heat transfer problem, early age concrete, evolutionary algorithm, FEM

1. Introduction

The proper determination of the thermophysical properties of hardening concrete plays a key role in the building the correct models of concrete structures. High temperature gradients associated with the exothermic chemical reactions of cement hydration may occur between the interior and the surface at the early age of concrete, when its strength is low [1]. Cracks occur, when temperature gradients cause tensile stresses, which exceed the tensile strength of the young concrete. Thermal distortions have greater influence on stresses especially for massive structures [2]. Thermophysical characteristics of concretes described by: thermal conductivity, specific heat and heat of cement hydration (reaction of cement with water), are evolving during hardening and depend on the maturity of concrete. Such parameters in practice can be determined by means of different experimental measurements (e.g. calorimetric), hot plate apparatus and several transient dynamic techniques. Thermophysical characteristics are identified in the paper by minimizing of a norm between measured and computed values of temperature. The minimization procedure is performed by means of an evolutionary algorithm. The evolutionary algorithm (EA), as the global optimization technique for searching parameters, which describe thermophysical properties of hardening concrete, is applied. Comparing to the use of conventional optimization methods, superiority of EA manifest in many aspects, e.g.: a fitness function has not to be continuous, information about objective function gradient is not necessary, choice of the starting point may not influence the convergence of the method, regularization methods in no needed [3, 4]. Applications of EA in identification problems give a great probability of finding of a global optimal solution.

2. Formulation of identification problem

From the mathematical point of view, the identification problem is expressed as the minimization of the defined functional. Following functional has been proposed:

$$\min_{\mathbf{x}} \quad f(\mathbf{x}) = \sum_{i=1}^{n} \sum_{i=1}^{m} \left(T_{ij}(\mathbf{x}) - \hat{T}_{ij}(\mathbf{x}) \right)^2 \tag{1}$$

where: n is a number of sensors, m is a number of time intervals, T_{ij} and $\hat{T}_{ij}$ represent computed and measured temperature values in particular point in time and space, respectively, $\mathbf{x}$ is a vector of design variables.

The vector of design variables $\mathbf{x}$ contains parameters, which define heat of hydration, specific heat and thermal conductivity. The identification problem is solved by finding the vector of design variables $\mathbf{x}$, by minimizing the functional (1). In-house implementation of EA, with the floating point gene representation is used. The solution of this problem is given by the best chromosome whose genes represent design. The general flowchart of EA is presented in Fig. 1.

Transient heat conduction equation in hardening concrete is defined in the form:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+q=\rho c_p\frac{\partial T}{\partial t} \qquad (2)$$

where: T - temperature of concrete $[\mathrm{K}]$, k - thermal conductivity, $\left[\frac{\mathrm{W}}{\mathrm{m\ K}}\right]$, x, y, z – spatial coordinates, q- internal heat source $\left[\frac{\mathrm{W}}{\mathrm{m}^3}\right]$, t- time [s], ρ – density of concrete $\left[\frac{kg}{\mathrm{m}^3}\right]$, c_p - specific heat of concrete $\left[\frac{\mathrm{J}}{\mathrm{kg\ K}}\right]$

Equation (2) allows to calculate the temperature in time and space, including proper definition of internal heat sources. Such sources represent the time rate of heat evolution by the hydrating cement.

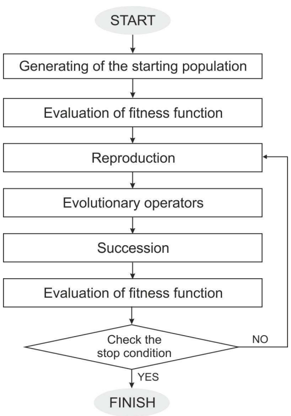
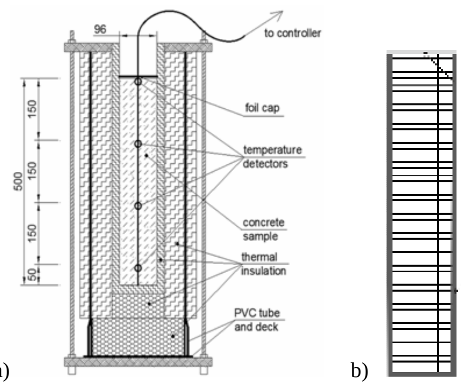


Figure 1: The flow chart of the evolutionary algorithm (EA).

3. Experimental measurement and numerical model

The temperature distribution in time is measured in the thermally-isolated cylindrical mould filled by the maturing concrete [6]. The sensor points, where temperature is measured (temperature detectors) are located along the longitudinal axis of cylindrical concrete specimen. Fig. 2a shows the schema of the mould with the positions of temperature sensors.



a) b)

Figure 2: a) The mould for temperature measurements, b) 2D numerical model with boundary conditions.

The problem of transient heat conduction is solved by means of FEM [5]. A two-dimensional numerical model of the hardening concrete specimen, consisting of 200 elements is prepared. Adiabatic boundary conditions are applied on the left, right and bottom segments of the boundary, whereas on the upper part, third type thermal boundary condition is applied (convection). An initial condition for the temperature is equal to 20^0C. The time of the analysis is 90 hours. The proposed method has been applied for identification of the thermal conductivity, the specific heat and the internal heat source. Additionally, the internal heat source includes the function of heat losses, which models the effect of an imperfect thermal isolation. Fig. 3 shows comparison of the temperature characteristic for exemplary mixture of concrete in the temperature sensor points.

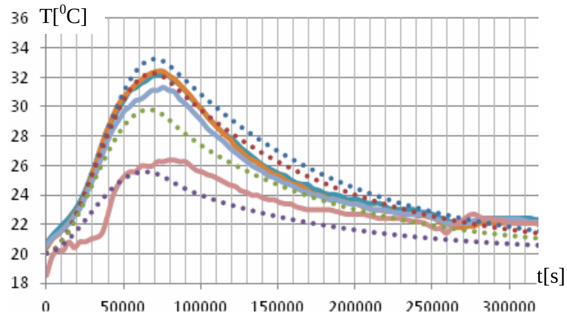


Figure 3: Comparison of the temperature characteristic for measured (solid lines) and indentified (dotted lines) of the temperature in sensor points.

4. Concluding remarks

The paper is devoted to identification of thermophysical properties of hardening concrete. The inverse problem was solved by minimization of the functional which represents a norm between calculated and measured values of temperature. The minimization problem was solved by means of the evolutionary algorithm. Detailed numerical results of identification problem are included in full paper.

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