Evolutionary computation in identification of thermophysical properties of hardening concrete

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Abstract

The evolutionary computation procedures in identification of thermophysical properties of hardening concrete in massive structures 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 of temperature fields is very important due to a link with 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: , heat of cement hydration, inverse heat transfer problem, early age concrete, evolutionary algorithm, finite element method, thermophysical properties of concrete.

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 of concrete structure at the early age, when the strength of concrete is low [1]. Cracks may 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 the thermal conductivity, the specific heat and the heat of cement hydration, 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 does not have to be continuous, information about objective function gradient is not necessary, a selection of the starting point may not influence the convergence of the method, regularization methods are not 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 the heat of hydration, the specific heat and the 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 [°C]
k - thermal conductivity, $\left[\frac{\mathrm{W}}{\mathrm{m\ K}}\right]$
x, y, z – spatial coordinates,
q- internal heat source $\left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$,
t- time [s],
– density of concrete $\left[\frac{kg}{\mathrm{m}^2}\right]$,
- specific heat of concrete $\left[\frac{\mathrm{W}}{\mathrm{kg\ K}}\right]$.

Equation (2) allows to calculate temperature in time and space, including a proper definition of internal heat source. The internal heat source is represented by the time rate of heat emitted by hydrating cement. The problem of transient heat conduction is solved by means of finite element method (FEM) [5]. Proper numerical model of the hardening concrete specimen is prepared. The obtained results were compared with experimentally measured temperature in concrete specimens [6,7].

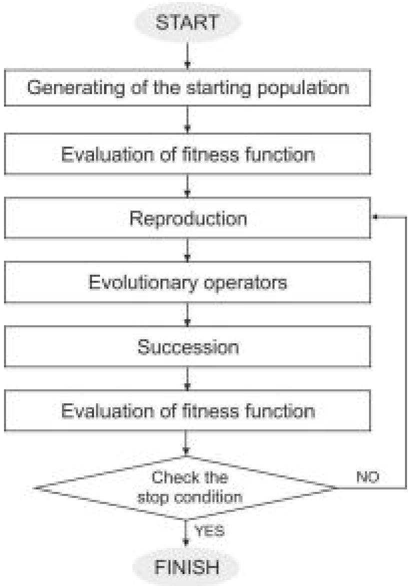

Figure 1: The flow chart of the evolutionary algorithm (EA)

3. Experimental measurement of temperature

One dimensional temperature distribution in time is measured in an axis-symmetric thermally-isolated cylindrical mould filled by fresh concrete. The sensor points, where temperature is measured (temperature detectors) are located along the longitudinal axis of cylindrical concrete specimen. Fig. 2 shows the schema of the mould with the positions of temperature sensors.

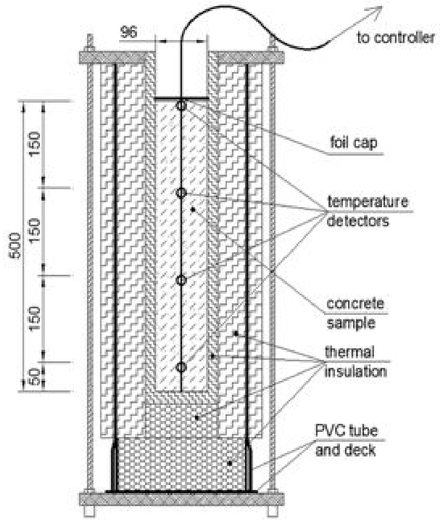

Figure 2: The cylindrical mould for temperature measurements

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. Numerical results of identification problem are included in the full paper.

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Acknowledgement: Project title “Durability and efficiency of concrete shields against ionizing radiation in nuclear power structures”, funded by NCBiR