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PREDICTING CHANGE OF CONCRETE AIR-FLOW PERMEABILITY DUE TO SELF-HEALING

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Abstract: Recently, the development of self-healing concrete has become an area of great attention. Achieving such a goal can save substantial repair costs and reduce worldwide green house gas emissions from new construction and repair work. In the present paper, the application of artificial neural networks (ANNs) to predict the self-healing of concrete is investigated. A hybrid genetic algorithm (GA) ANN model was developed based on data retrieved from the open literature. Results show that the proposed model can predict the self-healing of concrete with adequate accuracy.

1 INTRODUCTION

Concrete is the second most used material on earth after water. The vast majority of civil infrastructure around the world is built using concrete. From an ecological point of view, concrete is generally more sustainable than most other construction materials. However, concrete deteriorates over time, leading to substantial economic loss. According to Hume (2012), cities in Canada and the USA are estimated to face trillions of dollars in infrastructure deficit in the near future. A recent Canadian infrastructure report card showed that one-third of the municipal infrastructure is either in fair, poor or very poor condition. On the other hand, according to the 2013 ASCE infrastructure report card, the grade of the current USA national infrastructure condition is D+ (poor condition) based on capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation. It is estimated that by year 2020, $3.6 trillion dollars in investment is required to improve the condition of the American civil infrastructure, which has already reached a state of crisis, requiring substantial investment in research and development to reverse its continuous deterioration.

Recently, the concept of designing self-healing construction materials has become an area of great attention. Achieving such a goal can save trillions of dollars in repair costs and reduce worldwide CO_2 emissions. The self-healing concept can be defined as the ability of a man-made material to self-repair its cracks without external intervention (Blaiszik, *et al*., 2010; Ghosh, 2010). It is basically inspired by nature's healing processes, such as in human or animal tissue. For instance, when injured due to cuts, scrapes, or scratches, skin repairs itself through complex biological processes that can be divided into three stages: (a) inflammation, which starts immediately after the injury; (b) cell proliferation (growth of new tissue), which starts days after the injury and covers the major healing process; and (c) tissue remolding, which lasts for several months (Lorentz and Longaker, 2008). For a decade, several studies have tried to incorporate the concept of self-healing into different engineering materials, such as polymers, coatings, structural ceramics, concrete, ionomers, alloys, and metals. Although incorporating such an orchestrated biological healing process into a manmade material is still far from reality, data from several studies have shown promising results (Ghosh, 2010).

Concrete can heal its cracks based on different mechanisms including (a) further hydration of anhydrous cement, (b) carbonation, (c) expansion of the hydrated cement due to the swelling of C-S-H, and (d) precipitation of impurities from the ingress water and spalling of loose concrete particles in cracks (Edvardsen, 1999; Jacobsen et al., 1995; Hearn, 1998; Ramm and Biscoping, 1998). This type of self-healing is termed autogenous (or intrinsic) self-healing. In a previous study by Suleiman and Nehdi (2017), an artificial neural network based model was developed to predict the concrete self-healing in terms of crack-width change. In the present paper, a similar approach is adapted to develop a model capable of predicting the change of airflow permeability of concrete due to self-healing.

2 RESEARCH SIGNIFICANCE

The objective of this study is to develop a model capable of predicting the change in the air-flow permeability of concrete due to self-healing. This approach could exploit existing experimental findings for developing a predictive tool, which ultimately could form a basis for developing guidelines for the design and prediction of self-healing concrete in concrete.

3 NEURAL NETWORK ARCHITECTURE AND PARAMETERS

Figure 1 illustrates the architecture of the artificial neural network and **Table 1** exhibits the values of parameters used in this GA-ANN model. The model was developed based on the approach used in a previous study (Suleiman and Nehdi, 2017), which is essentially based on a trial and error since there is no optimal method for building a successful ANN. A genetic algorithm was implemented in the neural network to improve the prediction accuracy of the artificial neural network.

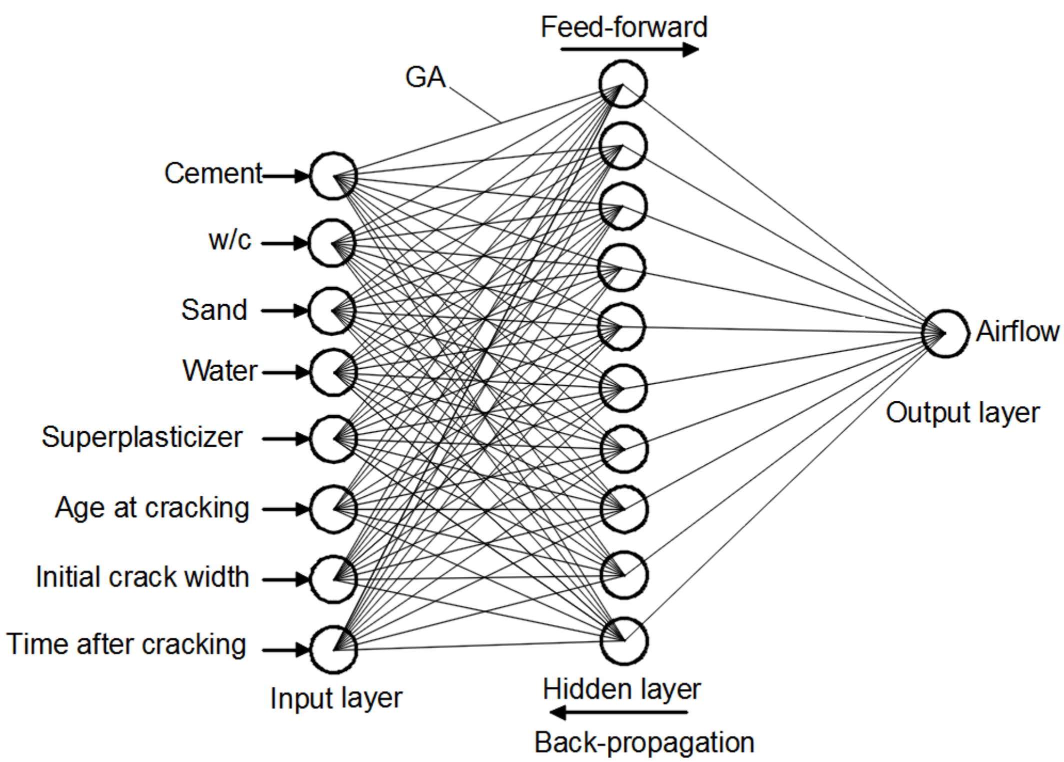

Figure 1: Architecture of ANN-GA Model.

Table 1: Values of parameters used in the GA-ANN model

Parameter	GA-ANN
Number of input layer neurons	8
Number of first hidden layer neurons	10
Number of output layer neurons	1

4 DATABASE SOURCES AND RANGE OF INPUT AND OUTPUT VARIABLES

The database was primarily collected from previous studies, particularly work reported by Gagné and Argouges (2012). They investigated the crack self-healing of pre-cracked cement mortars made with ordinary Portland cement. Samples were cracked by inducing a tensile stress at the age of 28 days and 6 months. The sizes of the created cracks were 50 ± 15, 105 ± 15, and 220 ± 35 µm. Results showed that cracks exhibited self-healing. However, the degree of self-healing depended on the initial size of the crack since small cracks (approximately 50 µm in width) completely healed in comparison to larger cracks. Therefore, as shown in Table 1, eight input parameters were used to train the GA-ANN. Seven of which contain the original mixture proportions in terms of portland cement dosage, water-to-cement ratio (w/c), sand, superplasticizer, age at cracking, initial crack width, and time after cracking. The corresponding airflow through crack was used as a single output.

Table 2: Range of input and output variables.

Database Parameter	Maximum	Minimum
Cement (g)	2800	2134
w/c	0.35	0.60
Sand (g)	6586	6220
Water (g)	1280	980
Superplasticizer (g)	43	0
Age at cracking (days)	180	30
Initial crack width (µm)	254	41
Time after cracking (days)	150	0
Airflow* (L/min)	13.40	0.00

*Output variable

5 TRAINING THE GA-ANN MODEL

The GA-ANN model was trained using randomly selected 70% of the total database, while 15% of the data was used for validation of the model and the other 15% was used for testing the generalization capability of the model. It should be emphasized that the 30% of the database used in validation and testing was unfamiliar to the model and not used in the training process. Back-propagation Levenberg–Marquardt rule (LMA) was used to simplify and shorten the training time. It basically propagates back the calculated error at the output layer to the network based on the Jacobian matrix *J*. The iteration of such an algorithm can be written as follows:

$$[1]\ w_{j+1} = w_j - [J^T J + \mu I]^{-1} J^T e$$

Where w_j is a vector of current weights and biases; μ is a learning rate; J is the Jacobian matrix; J^T is the transpose matrix of J; I is the identity matrix; and e is a vector of network errors.

6 RESULTS AND DISCUSSION

Figure 2 shows the predicted results of the change in airflow permeability due to self-healing by the proposed GA-ANN model versus the observed experimental measurements reported by Gagné and Argouges (2012). The performance of the GA-ANN model mainly depends on its ability to predict the experimental output data with reasonable accuracy. From the results shown, it can be observed that the proposed GA-ANN model captured the relationships between the provided input and output data with adequate accuracy, which indicates excellent performance. The reliability of the developed GA–ANN model for the complete data set was also evaluated via the coefficient of determination (R^2), as shown in the following equation:

$$[2] \quad R^2 = 1 - \left(\frac{\sum_{i=1}^{n} (t_i - o_i)^2}{\sum_{i=1}^{n} (t_i)^2} \right)$$

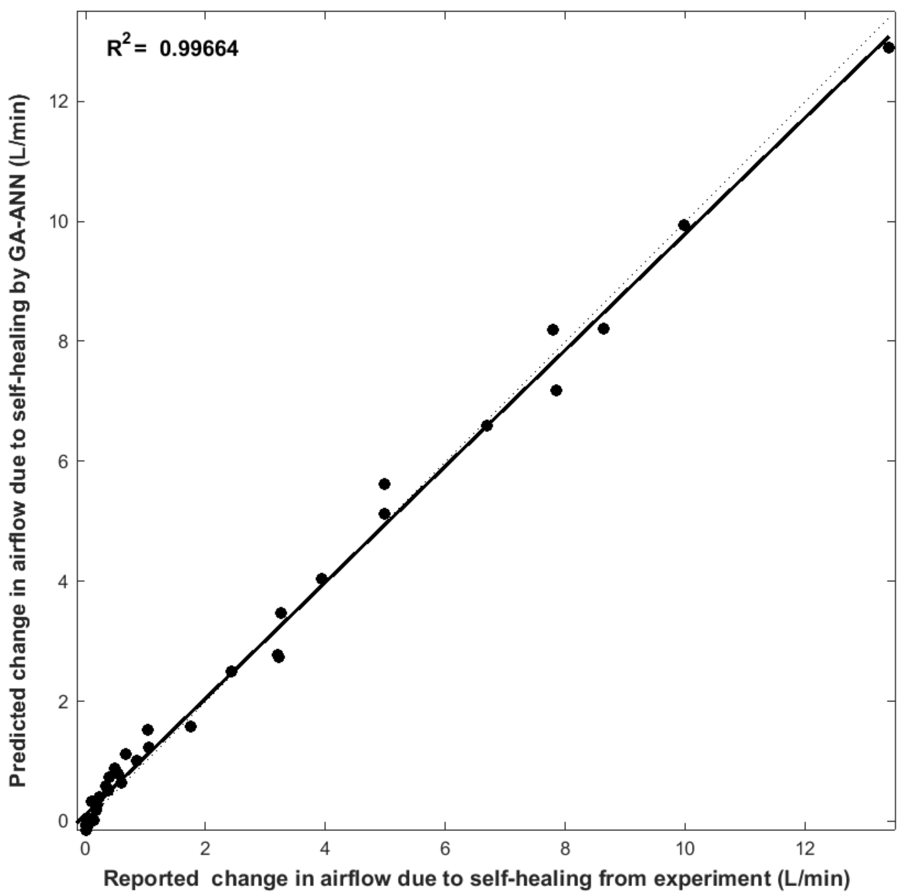

Figure 2: Regression plot of GA–ANN predicted change in airflow due to self-healing versus the corresponding experimentally reported change in airflow

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7 CONCLUSIONS

In this paper, a hybrid genetic algorithm–artificial neural network (GA–ANN) model was developed to predict the change of airflow permeability in pre-cracked concrete due to self-healing. The proposed model showed accurate predictions of the airflow change due to self-healing of concrete, which can be used to improve the durability design of concrete, leading to more sustainable infrastructure.

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