Available online at www.sciencedirect.com
ScienceDirect
Computational Materials Science 42 (2008) 74–82
COMPUTATIONAL MATERIALS SCIENCE
www.elsevier.com/locate/commatsci

Prediction of mechanical properties of recycled aggregate concretes containing silica fume using artificial neural networks and fuzzy logic

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Received 22 May 2007; received in revised form 11 June 2007; accepted 15 June 2007
Available online 3 August 2007

Abstract

Artificial neural networks and fuzzy logic have been widely used in many areas in civil engineering applications. In this study, the models in artificial neural networks and fuzzy logic systems for predicting compressive and splitting tensile strengths of recycled aggregate concretes containing silica fume have been developed at the age of 3, 7, 14, 28, 56 and 90 days. For purpose of constructing these models, experimental results for 210 specimens produced with 35 different mixture proportions were gathered from the literature. The data used in the artificial neural networks and fuzzy logic models are arranged in a format of eight input parameters that cover the age of specimen, cement, water, sand, aggregate, recycled aggregate, superplasticizer and silica fume. According to these input, in the artificial neural networks and fuzzy logic models are predicted the compressive and splitting tensile strengths values from mechanical properties of recycled aggregate concretes containing silica fume. In the models of the training and testing results have shown that artificial neural networks and fuzzy logic systems have strong potential for predicting 3, 7, 14, 28, 56 and 90 days compressive and splitting tensile strengths values of recycled aggregate concretes containing silica fume.

Keywords: Recycled aggregate; Compressive strength; Splitting tensile strength; Neural networks; Fuzzy logic

1. Introduction

For years people have been trying to keep the environment clean [1,2]. Recycle of solid wastes is also required to obtain a clean environment. For this reason, recycling of waste concrete is beneficial and necessary from the viewpoint of environmental preservation and effective utilization of resources. For the effective utilization of waste concrete, it is necessary to use waste concrete as recycled aggregates for new concrete [3]. Waste concrete disposal is difficult and economically onerous with regard to the difficulty in finding new landfill areas. Therefore, a strategy for satisfying all requirements seems to be recycling [4]. At present, utilization of recycled aggregate is limited mainly to subgrade of roads and filler works. For the utilization of recycled aggregates, increasing these usages areas is very important.

Several studies indicate that the presence of recycled aggregate in concrete seems to decrease the compressive and splitting tensile strengths as compared to that of conventional concrete. The decrease in strengths is due to the lack of bonding between recycled aggregate and Portland cement, and the high water absorption capacity of recycled aggregate. The use of silica fume in combination with a superplasticizer is now a usual way to obtain high-strength concretes. The improvement of mechanical properties of concretes with silica fume accounts for the increasing consumption of this admixture in concrete [5]. Mazloom et al. [6] indicate that as the proportion of silica fume increase, the workability of concrete decreases nevertheless its sort

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0927-0256/$ - see front matter
doi:10.1016/j.commatsci.2007.06.011

term mechanical properties such as compressive strength improves. In the study of Ajdukiewicz and Kliszczewicz [7], the six groups of specimen series with 35 different mixes have been obtained. It was designed that in first group of mix, six different mixes using merely granite or basalt as new aggregate; in second group of mix, six different mixes using recycled aggregate (2–16 mm) and new sand (0–2 mm); in third group of mix, six different mixes using fine and coarse recycled aggregate only; in fourth group of mix, five different mixes using merely granite or basalt new aggregate, with silica fume and superplasticizer; in fifth group of mix, six different mixes using recycled aggregate (2–16 mm) and new sand (0–2 mm), with silica fume and superplasticizer merely granite or basalt with silica fume and superplasticizer; in sixth group of mix, six different mixes using merely recycled aggregate with silica fume and superplasticizer. The compressive and splitting tensile strengths of concretes produced with recycled aggregates, silica fume and superplasticizer were significantly higher compared to the strengths of concretes produced with new aggregates. It was also concluded that the employment of silica fume and superplasticizer content in concrete produced by using recycled aggregate has a positive effect on increasing compressive and splitting tensile strengths. Topçu and Şengel [2] obtained the compressive strength of recycled aggregate concrete the recycled coarse aggregate replacement percentages of 0%, 30%, 50%, 70% and 100%, and they found that with the increase of recycled coarse aggregate amount, the values unit weight, compressive and flexural strengths decrease.

For the last two decades, a different modeling methods based on artificial neural networks (ANN) and fuzzy logic (FL) systems have become popular and has been used by many researchers for a variety of civil engineering applications [8–12]. ANN and FL are natural complementary tools in building intelligent systems. While ANN are low-level computational structures that perform well when dealing with raw data, FL deals with reasoning on a higher level, using linguistic information acquired from domain experts. The basic strategy for developing ANN and FL systems based models for material behavior is to train ANN and FL systems on the results of a series of experiments using that material [9–12]. If the experimental results contain the relevant information about the material behavior, then the trained ANN and FL systems will contain sufficient information about material's behavior to qualify as a material model [9,12]. Such a trained ANN and FL systems not only would be able to reproduce the experimental results, but also they would be able to approximate the results in other experiments through their generalization capability [8–12].

The aim of this study is to build models in ANN and FL systems to evaluate the effect of recycled aggregate, silica fume and superplasticizer on compressive and splitting tensile strengths of concrete. For purpose of constructing these models, 35 different mixes with 210 specimens of the 3, 7, 14, 28, 56 and 90 days compressive and splitting tensile strengths results of recycled aggregate concretes containing silica fume used in training and testing for ANN and FL systems were gathered from the technical literature [7]. In training and testing of the models the age of specimen (AG), cement (C), water (W), sand (S), aggregate (A), recycled aggregate (RA), superplasticizer (SP) and silica fume (SF) were entered as input; while compressive strength (f_c) and splitting tensile strength (STS) values were used as outputs. The models were trained with 140 data of experimental results and then remainders were used as only experimental input values for testing and values similar to the experimental results were obtained.

2. Artificial neural networks

Artificial neural networks (ANN) are an information processing techniques that is inspired by the way biological nervous systems, such as the brain, process information. The fundamental concept of neural networks is the structure of the information processing system [13]. Even an ANN quite simple and small in size when compared to the human brain, has some powerful characteristics in knowledge and information processing due to its similarity to the human brain. Therefore, an ANN can be a powerful tool for engineering applications [14]. In recent years, ANN have been applied to many civil engineering problems with some degree of success. In civil engineering, neural networks have been applied to the detection of structural damage, structural system identification, modeling of material behavior, structural optimization, structural control, ground water monitoring, prediction of experimental studies, and concrete mix proportions [15].

Neural networks are networks of many simple processing units, which are called neurons, with dense parallel interconnections. Each neuron receives weighted inputs from other neurons and communicates its outputs to other neurons by using an activation function. Neural networks might be single layer or multilayer [15]. The multilayer perceptron is the most widely used type of neural networks. It is both simple and based on solid mathematical grounds. Input variables are processed through successive layers of neurons. There is always an input layer, with a number of neurons equal to the number of variables of the problem, and an output layer, where the perceptron response is made available, with a number of neurons equal to the desired number of quantities computed from the inputs [13]. Layers between the input and output layers are called hidden layers and may contain a large number of hidden processing units [15]. All problems, which can be solved by a perceptron can be solved with only one hidden layer, but it is sometimes more efficient to use two hidden layers. Fig. 1 shows a typical architecture of a multilayer feed forward neural network with an input layer, an output layer, and two hidden layer. Each neuron of a layer other than the input layer computes first a linear combination of the outputs of the neurons of the previous layer, plus a bias. The coefficients of the linear combinations plus