Measurement 109 (2017) 137–148

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Concrete compressive strength detection using image processing based new test method ☆

Gamze Dogan [a], Musa Hakan Arslan [a,*], Murat Ceylan [b]

[a] Faculty of Engineering, Civil Engineering Department, Selcuk University, 42075 Konya, Turkey
[b] Faculty of Engineering, Department of Electrical-Electronics Engineering, Selcuk University, 42075 Konya, Turkey

ARTICLE INFO

Article history:
Received 7 April 2016
Received in revised form 23 March 2017
Accepted 16 May 2017
Available online 26 May 2017

Keywords:
Concrete
Mechanical properties
Image processing
Artificial neural network

ABSTRACT

Today, Artificial Neural Networks (ANN) and Image Processing (IP) are particularly used to solve engineering problems. This study uses ANN and IP together to determine the mechanical properties of concrete, such as the compressive strength, modulus of elasticity and maximum deformation, at a certain success rate. In other words, the primary objective of study is to predict the mechanical properties of concrete without causing destruction, using a new alternative method. In this context, using five distinctive parameters (water/cement ratio, curing, amount of cement, compression and additive), 96 cylindrical concrete samples were produced; images of the samples were taken before they were examined at the compression testing, and the training and testing procedures for ANN and IP were realized using the obtained pressure readings at the laboratory. In addition to 96 cylindrical concrete samples, 48 were randomly selected to verify ANN and IP. From both the training/test samples and the verification samples, there is a notably high correlation between the outcomes of ANN and IP and the actual results, which varies between 97.18% and 99.87%. When ANN and IP were used together, the described method is a good alternative to the traditional destructive and nondestructive methods that are currently used to identify the mechanical properties of concrete.

1. Introduction

Today, the image processing technique (IPT) and artificial neural network (ANN) are conveniently used in all areas of science. Particularly, these methods are used to address difficult-to-solve, time-consuming and high-cost engineering problems in the subdisciplines of civil engineering. Civil engineering researchers have frequently used these methods in studies of building materials, structural engineering and concrete technology [1–14].

Concrete is the most significant building material and has been studied for many years. The effects of its parameters on its mechanical behavior are studied, and theories on its mechanical behavior are continuously produced. The heterogeneous structure of this material and its non-linear behavior under load enhance its mystery. Nevertheless, some assumptions about the behavior of the concrete with reinforced concrete systems produce significant results such as cost effectiveness and seismic performance of the buildings.

Compressive strength of a concrete (f_c) is the main parameters of concrete since it affects other mechanical parameters directly. The obtaining of the compressive strength is quite easy than obtained other parameters for this reason after obtaining compressive strength with conventional test methods, other parameters such as tensile strength, elasticity modulus (E_c), ultimate deformation level (ε_{cu}), poison ratio (μ), tensile strength (f_{tc}) etc. can be assumed as simply formulations. It is well known that the modulus of elasticity (E_c) of the concrete increases as its compressive strength (f_c) goes up. It is possible to observe this fact at the typical stress-deformation graphic of the concrete. In general the value of the modulus of elasticity was obtained from the slope of concrete stress-strain graph at the $0.4f_c$ level. This assumption is generally used in reinforced concrete design. Besides, the value of concrete's ultimate deformation (ε_{cu}) is an also parameter that partially depends on the compressive strength. It is known that deformation value of the concrete decreases as its compressive strength rises. In the relevant literature there are some assumptions. In basis unconfined concrete ultimate deformation level is about 0.003–0.004 in building codes. There are several relationships between the compressive strength of concrete and its other mechanical

☆ This study was carried out within the framework of the Thesis Project No 13101007 supported by the Selcuk University Unit of Scientific Research Projects Coordination.

* Corresponding author.
E-mail addresses: gamze@selcuk.edu.tr (G. Dogan), mharslan@selcuk.edu.tr (M.H. Arslan), mceylan@selcuk.edu.tr (M. Ceylan).

http://dx.doi.org/10.1016/j.measurement.2017.05.051
0263-2241/

Nomenclature

f_c	is the strength of concrete	$t(i)$	is the desired output values
ε_{cu}	is the ultimate deformation of concrete	$a(i)$	is the neural network outputs
E_c	is the modulus of elasticity at age of 28 day	k	is number of data points in the training and testing data
ANN	artificial neural network	x	is number of segments in the training and testing data
IP	image processing	y	is the neural-network outputs for the training and testing procedures
R^2	regression analysis		
l_r	is the learning ratio		

characteristics. Compressive strength of concrete can be accepted as the highest strength which the concrete gains. Since the design of the reinforced concrete buildings is based on the maximum stress that the concrete can bear, it is very important to measure the compressive strength of the concrete properly.

To study the compressive strength and other mechanical properties of concrete, various test methods are used, such as core drilling, ultrasonic pulse velocity, Schmidt Hammer and electrical resistivity measurement [15–18]. These experiments are divided into two groups: destructive (damaged) and non-destructive (undamaged), according to the type of application. Although these experiments are usable alone, they can also be combined. The error rates of the methods vary between 4% for combined use and 15% for individual use [15,16]. In addition to the current methods, the main purpose in the studies that are performed on concrete using IP and ANN is to define the mechanical features, aggregate dispersion and amount of space of concrete faster, more accurately and more practically. Basyigit et al. [19] estimated the concrete compressive strengths with an accuracy of 94.82% using IP.

Özerkan [20] specified the characteristics of self-settled concrete air gap with volatile ash using IP. Lopez et al. [21] used image analysis to examine the shrinkage, unit deformation, yield and elasticity of high-performance lightweight concrete. Nambiar and Ramamurthy [22] used the IP method to examine the effects of the air gap amount in foam concrete on the concrete strength and density In literature, there are various concrete studies about IP [23,24].

Dantas et al. [25] studied the prediction of the compressive strength of concretes with construction and demolition waste using ANN. Kim et al. [26] used the probability-based neural-network structure to estimate the compressive strength of concrete. ANN is a notably convenient and efficient method in predicting the concrete compressive strength. Alshihri et al. [27] investigated the ANN-aided estimation of the compressive strength of lightweight concrete that was exposed to distinctive curing conditions. Oreta and Kawashima [28] used ANN to predict the confined compressive strength, and the corresponding strain of circular concrete columns was explored. Bildik [29] worked on a mixture calculation for the normal pressure strength concretes to be modeled by ANN. Moreover, compression tests were performed in these studies for distinctive water/cement ratios to enable mixture computation for fiber-reinforced concretes. In addition, the outcomes of the tests were trained using ANN, and the effect of steel fibers on the collapse was examined. Gupta et al. [30] used ANN to obtain more accurate concrete strength prediction based on parameters such as the mixture design, concrete size, specimen shape, curing technique, curing period, environmental conditions, etc. In the works that applied ANN, the approach yielded greater improvements in performance than other approaches in identifying the mechanical properties of concrete. In literature, there are different concrete studies about ANN as well [31,32].

In the present study, a new nondestructive experimental method that uses IP and ANN together was proposed for some partially interdependent mechanical features such as the concrete strength, modulus of elasticity and maximum deformation. The training and testing operations were accomplished using 96 cylindrical samples, which were produced according to different parameters such as the water/cement ratio, amount of cement, compaction and additives. Then, the results that were obtained from the compression testing of 48 cylindrical concrete samples which were produced without certain dependent parameters and the estimated values of ANN and IP were verified. The fundamental objective of the works is to approximate the mechanical properties of concrete using an alternative method of ANN and IP without causing any damage.

2. Image processing technology and artificial neural networks

A picture can be converted into digital form. This conversion is called digitizing. Various programs, such as MATLAB, are used to digitize images. Using these programs, an image file is taken to the application medium in a matrix. The operations that are performed on this matrix can display the picture as a matrix, each element of which is called a pixel which is obtained by applying the operations and algorithms on the matrix. The number in each pixel in a digital image reflects the brightness at that point. The digital equivalence of a physical image is provided in Fig. 1.

Image processing methods include many processes such as image provision, image digitalization, segmentation, image enhancement, classification, recording and recalling. Image processing is used in medicine and biology for processing and assessment, in physics and engineering for processing electron microscopy and spectrometric images, in aerospace and aeronautics for processing satellite, and radar images and their assessment [33].

The matrix obtained by digitizing the image can be used to solve problems if it is used together with various methods such as ANN. ANN is a logical programming technique that was developed by taking the human brain as an example for its working mechanism and implementing its basic operations in software. The software is an algorithm that can perform the duties of the brain (make decisions, conclude) using a computer if there are no data, reach a result based on the existing information, accept continuous data entry, learn and recall. Although ANN exhibit similarities to only some functions of the real nerves, they were developed by modeling the biological neural structure. There is more than one input and one output per nerve to make up the foundation of the ANN.

3. Creation of data set

Obtaining the desired performance level for algorithms such as ANN considerably depends on the selected data, the data exchange interval during operation and number of data. To identify the mechanical features of concrete from images using IP and ANN in this study, the following cylinder samples were produced [34].