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Technical Report

Effect of specimen size and shape on compressive strength of concrete containing fly ash: Application of genetic programming for design

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ABSTRACT

The use of fly ash as a mineral admixture in the manufacture of concrete has received considerable attention in recent years. For this reason, several experimental studies are carried out by using fly ash at different proportions replacement of cement in concrete. In the present study, the models are developed in genetic programming for predicting the compressive strength values of cube (100 and 150 mm) and cylinder (100 × 200 and 150 × 300 mm) concrete containing fly ash at different proportions. The experimental data of different mixtures are obtained by searching 36 different literatures to predict these models. In the set of the models, the age of specimen, cement, water, sand, aggregate, superplasticizers, fly ash and CaO are entered as input parameters, while the compressive strength values of concrete containing fly ash are used as output parameter. The training, testing and validation set results of the explicit formulations obtained by the genetic programming models show that artificial intelligent methods have strong potential and can be applied for the prediction of the compressive strength of concrete containing fly ash with different specimen size and shape.

1. Introduction

Environmental pollution of industrial waste has become an important problem in recent years which is potentially damaging to both the environment and human health. New trends in environmental regulations related to disposal of wastes such as fly ash (FA), silica fume or granulated blast furnace slag have begun increasing interests in using the wastes as construction materials partially replacing Portland cement in concrete [1]. FA is the byproduct of the burning of pulverized coal and is collected by mechanical and electrostatic separators from the fuel gas of power plants where coal is used as a fuel [2]. A material, which forms of environmental pollution, is evaluated by using FA in concrete production. FA has been commonly used to replace part of cement in concrete, and the percentage of replacement ranges from about 20% (low volume FA) to more than 50% (high volume FA) of the total cementitious materials [2,3]. Furthermore, if the early strength is not an important factor, FA can be used as high as 70%. This replacement rates is determined by a variety of experimental studies.

FA improves the some properties when used in concrete as a replacement of cement. When producing concrete containing FA or building concrete containing FA structures, it is necessary to predict the mechanical properties of concrete containing FA such as compressive strength (f_c), flexural strength, splitting tensile strength, modulus of elasticity, creep, durability, shrinkage, etc. Among the mechanical properties used in design, f_c is most important since other properties can be predicted on the basis of f_c [1].

Artificial neural networks and fuzzy logic methods are commonly used in the many of civil engineering applications. In addition, gene expression programming (GEP) has also been used for civil engineering applications in recent years. In the present study, four different models have been developed for predicting the f_c values of concrete containing FA with different size and shape. The f_c values of cube and cylinder concrete containing FA at different proportions are predicted by the models developed in GEP method. In GEP method, the models were developed to predict the f_c values of (100 and 150 mm) cube concrete, and also (100 × 200 and 150 × 300 mm) cylinder concrete, respectively. The developed GEP models were named as GEP-I, GEP-II, GEP-III and GEP-IV, respectively. The age of specimen (AS), cement (C), water (W), sand (S), aggregate (A), superplasticizer (SP) and fly ash (FA) were used as input variables in training, testing and validation sets of the GEP models, while the f_c values were used as output in the training set. In addition to these input variables, CaO was used in the fourth model.

The reason of the development four different models in this study is that the size and shape of the specimens significantly affect the results of f_c test which is commonly used in the quality control procedures of concrete. Because of the size and shape

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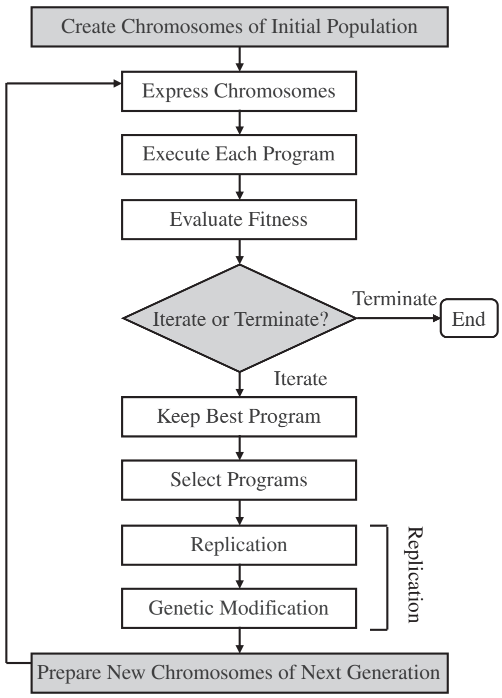

Fig. 1. The flowchart of a gene expression algorithm [4].

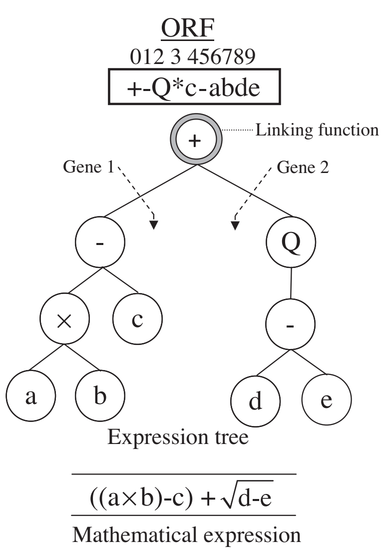

Fig. 2. Chromosome with two genes and its decoding in GEP.

Table 2
GEP parameters used for proposed formulas.

	Parameter definition	GEP-I	GEP-II	GEP-III	GEP-IV
p_1	Number of generation	764	801	795	763
p_2	Arithmetic operators	+, −, *, /	+, −, *, /	+, −, *, /	+, −, *, /
p_3	Mathematical functions	Sqrt, 3Rt, 4Rt, Sub3, Exp, x^3, Add3, $1/x$, Ln	Sqrt, x^2, Exp, 3Rt, 4Rt,	Sqrt, Mul3	x^2, x^3, Sqrt, Mul3, Add3, 4Rt
p_4	Number of chromosomes	20	30	40	30
p_5	Head size	10	10	10	10
p_6	Number of genes	5	4	4	4
p_7	Linking function	Multiplication			
p_8	Mutation rate	0.044			
p_9	Inversion rate	0.1			
p_{10}	One-point recombination rate	0.3			
p_{11}	Two-point recombination rate	0.3			
p_{12}	Gene recombination rate	0.1			
p_{13}	Gene transposition rate	0.1			

effect, the relative strength of concrete shows variability for different dimensions and forms of the specimens. This variability is clearly observed in the made experimental studies and the references used for create models. Besides, these models are developed for eliminating loss of time and materials by predicting the f_c values of concrete containing FA without experimental study.

2. Gene expression programming

Gene expression programming (GEP) is, like genetic algorithms (GAs) and genetic programming (GP), a GA as it uses populations of individuals, selects them according to fitness, and initiates genetic diversity using one or more genetic operators [4]. GEP algorithm is a wide range of functions scans as a combination of GA and GP algorithms. The flowchart of a gene expression algorithm is shown in Fig. 1. A large portion of the flowchart in GEP algorithm constitutes the genetic operators.

Table 1
The data set of the proposed GEP models.

The model information		Training set	Testing set	Validation set
GEP-I	Number of data set	270	136	166
	References	[3,6–11]	[3,6–11]	[12–15]
	Age of specimens	3, 7, 14, 28, 56, 60, 90, 180, 365		
GEP-II	Number of data set	107	53	114
	References	[2,16–20]	[2,16–20]	[21,22]
	Age of specimens	7, 14, 28, 56, 90, 91, 112, 180, 360, 365, 720		
GEP-III	Number of data set	278	140	166
	References	[1,23–26]	[1,23–26]	[3,27–31]
	Age of specimens	1, 3, 7, 14, 21, 28, 56, 90, 91, 180, 182, 364, 365		
GEP-IV	Number of data set	312	154	80
	References	[32–37]	[32–37]	[38]
	Age of specimens	3, 7, 14, 28, 56, 90, 91, 365		