Multivariate Adaptive Regression Splines for Compressive Strength of Self-Compacting Concrete Modeling and Prediction

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1. INTRODUCTION

Concrete is one of the most important materials in construction. In recent years, researchers have conducted various investigations on different types of concretes [1]. Introduction of self-compacting concrete has brought huge technological advances. Use of SCC facilitated the concrete placing between the rebars, without need of external vibration, and just through the weight of concrete itself. Utilizing self-compacting concrete results in reducing construction time and cost in addition to reducing the noise in construction sites [2]. Concrete workability is an important factor for proper execution, which after widespread application of reinforcing bars in concrete in the beginning of the 20th century and necessity of utilizing high workability concrete, it was maintained for a long time by addition of water to the cement. But in latter research it was found that use of high amounts of the water and cement would bring about negative results [3]. In self-compacting concrete, super plasticizers and binder materials are important to achieve high workability and proper viscosity while eliminating the separation, and some solutions for optimal mix design of concrete like reducing the aggregate to cement materials ratio, increase in the amount of cement- paste with a certain water to cement ratio, and control of the largest coarse aggregate size have been proposed [4]. The volume of binder materials used in self-compacting concrete, in comparison to conventional concretes, is higher and this indicates the importance of utilizing proper type of the material and weight combination of these materials to provide higher durability and strength of concrete and also its corresponding effects like reduced generation of pollutant gazes during cement production and participation in the sustainable development [5]. With respect to this issue that consumption of high amounts of cement and super plasticizers requires huge expenses, utilization some alternative supplementary cementitious materials (SCMs) like metakaolin as a replacement for Portland cement has been in consideration. The environmental concerns over extraction of raw materials and emission of CO2 during cement production; urge us to reduce the amount of consumed cement by application of additives. Utilizing metakaolin increases the concrete strength and durability against chemical attacks, alkali silica reaction and freeze-thaw cycles. Metakaolin also is effective in some mechanical properties of concrete including compressive strength, early age and flexural strength [6-12]. The wide range of materials and substances used in this type of concrete and complexity of its corresponding mix design which is affected by various parameters, also difficulty in finding existing relationships between these parameters have made it necessary to present a model for mix design of the self-compacting concrete incorporated metakaolin. Today, utilizing the artificial intelligence methods for modeling and predicting problems in civil engineering has become widespread due to their advantages. The experience and studies of the researchers have revealed that in addition to various experimental research works, use of various artificial intelligence methods in investigating and predicting the fresh and hardened properties of the concrete has become a necessity [13-18]. There is limited research literature concerning modeling of the metakaolin contained self-compacting concrete. Safarzadegan Gilan et al. utilized the SVR-PSO hybrid method and also ANFIS method for predicting the compressive strength and RCPT test of 25 samples of metakaolin contained self-compacting concrete at ages of 7, 28, 90 and 180 days. The results exhibited the desired and highly accurate performances of both models [19]. Sarıdemir modeled 179 mortar samples containing metakaolin utilizing the two artificial intelligence methods. The results of the statistical error indices in 60 test samples and 119 trained data, reported significant precision and validity of both methods in predicting the compressive strength [20]. In this study, the effect of largest grain size in the mix design (D_{max}) also was investigated for the first time as an input in the modeling of concrete and predicting behavior of the self-compacting concrete. The main goal in this paper is utilizing the

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novel methods (MARS) in the field of modeling and predicting the concrete properties. Hence, with respect to the limited artificial intelligence research conducted on the metakaolin contained SCC, this type of concrete was selected for development of the proposed models.

2. MULTIVARIATE ADAPTIVE REGRESSION SPLINES

Multivariate adaptive regression splines (MARS) is first introduced by Friedman in 1991. It is a flexible method to organize relationships that are nearly additive or contain interactions with fewer variables. MARS does not have any assumption about the underlying functional relationship between input and output variables [21]. One main advantage of MARS is its ability to estimate the contributions of basis functions in order that the additive and interactive predictors' effects are allowed to determine the response variable (Cheng and Cao, 2014). The MARS technique produces flexible regression models. In these models, the solution space is split into various intervals of predictor variables and individual splines are fit to each interval [21].Each spline function is defined on a given interval and the end points of the interval are called knots. The MARS composed of two stepwise procedures. In forward step, an over-fitted model, with too many extra knots is developed. A pruning procedure is employed to remove redundant knots in backward step. The function projects variable X to a new variable Y by using the following two functions as follow (equation 1 and 2) [22]

$$Y - \max(0, X - c)$$
$$Y - \max(0, c - X)$$

where c denotes some selected threshold value. To keep going the continuity of the basis functions, two close splines are intersect at a knot. Thus, the function is applied in a forward and backward stepwise method to each input variable to identify the location of knots where the function value varies [23] Further details of an MARS can be obtained from jekabsons [22].

3. DATA SET

In this paper, a collection of data points (117 distinctive data records) obtained from published literature were used to develop a technique for estimating the CS_{28} of SCC [24-33]. In many cases, there is an economic benefit of price differential between cement and SCMs. Furthermore, partial substitution of cement allows a considerable decrease in the quantity of the chemical admixture [12]. Behavior prediction of the compressive strength of SCC is basically more difficult than ordinary concrete. In this paper, the MARS technique is used to obtain meaningful relationships between the 28-days compressive strength of SCC mixture and the influencing parameters as follows:

$$CS_{28} = f\ (\mathrm{C, W, MK, SP, B, C.A/F.A, D\ max}) \qquad (3)$$

Where C (kg/m^3), W (kg/m^3), MK (kg/m^3), SP (kg/m^3), B (kg/m^3), C.A/F.A (kg/m^3), D_{max} (mm) are the cement, water, metakaolin, super plasticizer, binder, coarse aggregate to fine aggregate ratio, and largest aggregate size in the mix design, respectively.Fig.1 illustrates the histogram of the parameters in this study.