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Investigation of performances of some empirical and composite models for predicting the modulus of elasticity of high strength concretes incorporating ground pumice and silica fume

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HIGHLIGHTS

- Investigating the usage of empirical and composite models for pumice and silica fume concrete.
- Developing an approach to predict modulus of elasticity when pumice and silica fume properties are not clear.
- Discussing the elastic behavior of high strength concretes with ground pumice and silica fume in the terms of model performances.

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ABSTRACT

In recent times, the importance of constructing different models to predict the elastic properties of concrete have become common. The objective of this study is to investigate the performances of some empirical and composite material models to predict the modulus of elasticity of high strength concrete (HSC) with ground pumice (GP) and silica fume (SF). The experimental compressive strengths and unit weights of these high strength concretes, are used in the calculations of the modulus of elasticity of concretes by common empirical models. Then, modulus of elasticity of same HSCs are also predicted using some common composite material models. Finally, all model predictions are compared to the experimental modulus of elasticity of high strength concretes. The performances of all models are discussed. Consequently, both empirical and composite material models can be employed to predict the modulus of elasticity for GP and SF concretes, using the assumptions in this study.

1. Introduction

The modulus of elasticity is the most important parameter for determining the strain behavior of concrete [1]. Many studies have been made to investigate the elastic behavior of different concrete types. For instance, Toumi et al. [2] have investigated the effects of fiber reinforced cement based mortars as thin bonded overlay materials with low modulus of elasticity on the repair of old concrete. Zhou et al. [3] have investigated the effects of different coarse aggregate types on modulus of elasticity of high performance concrete. Ramesh et al. [4], studied the effect of the elastic moduli and volume fraction of the transition zone on overall elastic moduli of concrete or mortar. Boulay et al. [5] have developed a methodology and an apparatus to monitor the modulus of elasticity, compressive and tensile strengths of concrete, automatically since the earliest age. Simeonov and Ahmad [6] reported the effect of transition zone on the elastic behavior of concrete. It also has been reported that the low modulus of elasticity may decrease the cracking susceptibility [7–10]. It can be said that the elastic behavior and the Modulus of elasticity of cement, mortar and concrete is necessary to be investigated in concrete science. The findings of these studies are not concerns of this modelling study, however, it seems that modulus of elasticity of concrete is worth to investigate. Even, modelling this property is an important issue.

Additionally, determining, estimating and predicting the modulus of elasticity is still taking attention of many researchers. Some composite material models and some empirical models have been developed in order to predict or analyze the elastic properties of different concrete types such as dam concrete, rubberized concrete, ordinary concrete containing different types of aggregates and cements, slag concrete, and structural lightweight aggregate concrete [1,11–18]. Other studies, using different parameters, have also been reported in order to estimate or predict the modulus of elasticity of different cement, mortar and concrete composite

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materials. For instance, Lee et al. [19] have developed a multiscale chemo-mechanical model to predict the temperature independence and thermal gradation of the concrete Modulus of elasticity at three scales of observations as the level of concrete, the level of mortar and the cement paste level. The model has been compared to the data in literature and the test data. The results showed that the model can be used to predict the modulus of elasticity of concrete for high temperatures. Demir [20] has proposed a model based on fuzzy logic for estimating the modulus of elasticity of normal and high strength concretes and the proposed model has used the compressive strengths of concrete and the performance of fuzzy model was good. Zhao et al. [21] has suggested a two composite material sphere model and a two-step approach (thermal decomposition or microcracking effects) for predicting and evaluating the modulus of elasticity of heated cement paste with or without SF up to 600 °C. Lee and Park [22] have developed a numerical model with three phase model and finite element considering discontinuity for evaluating concrete with complex interfacial transition zone in three dimensions.

In addition to these studies, Guan et al. [23] have suggested a stochastic multiscale computational model to estimate the fiber reinforced concrete's (FRC) mechanical properties exposed to tensile loading. This model has three stages such as the microscale, the mesoscale and the macroscale stages. Like the previous studies, the numerical results of this model for FRC's modulus of elasticity were compared to experimental results. It has been reported that the suggested stochastic multiscale computational method is appropriate for determination of this mechanical property [23]. Another two-step analytical procedure is proposed by Li et al. [24]. to evaluate the quantitative influence of the maximum aggregate size and aggregate gradation on the effective Young's modulus of concrete. Likewise, the calculated predictions have been compared with experimental results from the literature and the comparison results were in accordance with literature when is strain is assumed for every basic element in the second step. Another paper investigated the enhancements and predictions of the Modulus of elasticity of palm kernel shell concrete [25]. Further, the effect of varying sand and palm kernel shell contents and mineral admixtures on compressive strength and modulus of elasticity was investigated. Furthermore, the proposed equation based on Comite Euro-International Du Beton/Fédération internationale du beton (CEB/FIP) Model appears to predict the modulus of elasticity close to the experimental values [25]. In a previous article, a differential effective medium theory (D-EMT) is applied assigning modulus of elasticity to corresponding bulk paste matrice, Interfacial Transition zone and aggregate and, like the other modelling studies in literature, the performance of this model was quite appropriate for a variety of many different concrete types [26]. Another paper observed the increase of the elastic properties of a cement paste during its hydration [27]. The homogenization theory model was deployed and the prediction results for the effective Young's modulus, during later hydration ages and at the end of hydration, have been excellent when compared to the experimental results available in the literature [27].

Similarly, the modulus of elasticity and the tensile strength of self-compacting concrete are evaluated by Craeye et al. [28], collecting results from 250+ articles in literature, and the collected results compared with those predicted from the formulations and existing models according to Eurocode 2 and the Model Code (MC 90 and MC 2010). An innovative multi expression programming approach was developed with new predictive equations for tangent Modulus of elasticity of normal strength concrete and high strength concrete. The method uses the concrete compressive strength like many previous empirical models and the proposed model was more effective and accurate than previous models [29]. Additional three phase homogeneous composite material examinations and considerations for ordinary concrete using a numerical-statistical also have been made [30]. Behnood et al. [31] has recommended a model in order to predict the modulus of elasticity of recycled aggregate concrete using M5' model tree algorithm. In another study, a model predicting the elastic properties of unsaturated concrete such modulus of elasticity and poison's ratio [32]. In this manner, there are many studies, in literature, which the modulus of elasticity of different concrete types, such as normal and high strength concretes, low strength mortars, recycled aggregate concretes, and calcium hydroxide, have been predicted by using different methods like artificial neural network, support vector machine, adaptive neural fuzzy inference systems, optimal nonlinear regression models, micromechanical based theory, fuzzy logic, etc., [33–39]. The performances of these models are mostly quite well and they can predict the modulus of elasticity of concrete without making any experiments. Besides, these models make it easy to examine, investigate, understand and evaluate the elastic behavior of different concrete types. In this way, new Modulus of elasticity prediction models using different approaches and methods are continued to be developed. Besides, it seems that developments of such prediction or estimation models will be more demanding for further years.

On the other hand, there are sufficient numbers of studies about GP and SF, as mineral admixtures and cement additives, effects on fresh and hardened properties of different concretes types [40–64]. Thus, the properties of many different concrete types produced with GP and SF admixtures/additives are widely reported.

In this paper, the properties of GP and SF concrete series in a previous article [64] are considered to be used for the prediction of modulus of elasticity of GP and SF concretes. The compressive strengths and unit weights of these series are used as input data or parameters for empirical models proposed by some specifications or studies. Besides, volume fractions, which were obtained using mixture proportions, and experimental modulus of elasticity of these GP and SF concrete series [64] were used as input data for composite material models. The elastic moduli of these series have been predicted or estimated using 6 different empirical models and 10 different composite material models. After then, the predicted modulus of elasticity results of empirical and composite material models is compared with the experimental elastic moduli of these series reported in this previously published reference article [64]. Finally, the performance of 16 different models were discussed and evaluated. The models, which can be used for accurate and precise prediction of GP and SF concretes, are attempted to be presented.

2. Modelling approach

The mixture proportions of GP and SF concretes taken from the reference study are given in Table 1 [64]. The experimental compressive strengths, unit weights and modulus of elasticity of those GP and SF concrete series are also presented in Table 2 [64]. In Tables 1 and 2, GP and SF concrete series are indicated as mixture codes which are explained below. The specific gravities of cement, superplasticizer (SP), GP, SF and aggregates [64], to calculate these ingredient volumes in the mixtures, are given in Table 3.

In the reference paper, three series of concrete mixtures, which was apart from the control concrete mixture, were prepared and tested to evaluate the f_c and E_c. A total of 22 concrete mixtures were prepared. In the first and second series, SF and GP were used to replace 5%, 10%, 15%, 20% and 25% by weight of Portland cement. In the third series, SF was used together with GP to replace different ratios (2.5%SF + 2.5%GP; 5%SF + 5%GP, 5%SF + 10%GP, 5%SF + 15%GP and 5%SF + 20%GP; 10%SF + 5%GP, 10%SF + 10%GP and