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ORIGINAL ARTICLE

Statistical analysis of the effective factors on the 28 days compressive strength and setting time of the concrete

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ABSTRACT

In this study, the effects of various factors (weight fraction of the SiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O, CaO, MgO, Cl, SO_3, and the Blaine of the cement particles) on the concrete compressive strength and also initial setting time have been investigated. Compressive strength and setting time tests have been carried out based on DIN standards in this study. Interactions of these factors have been obtained by the use of analysis of variance and regression equations of these factors have been obtained to predict the concrete compressive strength and initial setting time. Also, simple and applicable formulas with less than 6% absolute mean error have been developed using the genetic algorithm to predict these parameters. Finally, the effect of each factor has been investigated when other factors are in their low or high level.

Introduction

Cement is a mixture of complex compounds. The reaction of cement with water leads to setting and hardening. Concrete is an important structural material being used in most of the construction industry and the setting time and strength are two of the most important properties for its quality. The mixture of the initial mineral materials should have a certain composition to lead a suitable setting time and compressive strength after passing high temperatures in the furnace and then mixing with water. This certain composition of mineral materials is being estimated by different modulus such as SiO_2, Al_2O_3 or hydraulic modulus. These moduluses determine the quantity of the initial materials composition to reach a suitable strength and setting time. Some recent articles have described effect of various parameters on the strength of the concrete using the fuzzy logic [1–9]. However statistical analysis has been used rarely to study effect of raw materials composition on the strength and setting time of concrete. In the previous study, a fuzzy logic model was designed and

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optimized to estimate the compressive strength of 28 days age concretes [8]. Input variables of the fuzzy logic model were the water to cement weight ratio and coarse aggregate to fine aggregate weight ratio, whereas the output variable was 28 days concrete compressive strength (*CCS*). Another study investigated effects of these input variables on the compressive strength of various ages of the concrete [9].

The effect of the initial materials on the CCS and IST was investigated in some of the previous studies through four clinker phases, weight percent of CaO, SiO_2, Al_2O_3, and Fe_2O_3 components [10–12]. Other initial materials such as Na_2O, K_2O, MgO, Cl and SO_3, which usually have a low weight percent in the cement, can have important effects on the CCS and also IST, which should be determined [13–18]. Cement physical properties such as Blaine value also have a special effect on the CCS and IST [17–22]. The Blaine values of the initial materials indicate the specific surface area and also the volume of the cement particles. The role of this physical parameter on the CCS and IST should be investigated to have a suitable predictive model for these two objective parameters.

In the present study, effect of the initial materials composition and Blaine of the cement particles on the compressive strength and initial setting time (*IST*) of concrete has been analyzed by statistical methods through 663 experiments on the raw materials and concrete. The aim of this investigation is presenting empirical equations to calculate confidentially values of these two important parameters verses composition and Blaine of the initial materials. The range of the raw materials composition of Portland cement (type II) during the experiments was as follows: SiO_2 (20.23–22.24)%, Al_2O_3 (4.25–5.1)%, Fe_2O_3 (3.65–4.38)%, CaO (61.43–65.31)%, MgO (1.03–1.79)%, SO_3 (2.1–3)%, Na_2O (0.45–0.76)%, K_2O (0.58–0.77)%, Cl (0.002–0.044)%, and about 2% of the other materials. The raw material Blaine was in the range of 2820–3280 cm^2/gr. Finally, impacts of each effective factor are investigated when the other factors are fixed in a high or low level.

Experimental

The method of determining compressive strength and also initial setting time of cement are described in this section. The laboratory where preparation of specimens took place was maintained at a temperature of 20 °C and a relative humidity of more than 50%.

The specimens were cast from a batch of mortar containing one part cement, three parts Germany Standard sand and one half part of water. The Standard sand is natural, siliceous materials consisting of rounded particles with at least 98% silica. The cement was exposed to ambient air for the minimum time possible. It was stored in a completely filled and airtight container which is not able to react with cement. The mortar was prepared by mechanical mixing as shown in Fig. 1 and was compacted in a steel mold using a jolting apparatus. The jolting apparatus consisted of a rectangular table rigidly connected by two light arms to a pivot at 800 mm from the center of the table.

The mold was consisted of three compartments so that three specimens 40 mm × 40 mm in cross section and 160 mm in length can be prepared simultaneously. The specimens were stored in the mold in a moist atmosphere (20 °C and a relative humidity of more than 90%) for 24 h. After demolding, the specimens were put in water until strength testing.

Fig. 1 Mechanical mixer used for preparation of specimens.

The initial setting time of the prepared samples was measured by the vicat apparatus. TONI TECHNIK Company was brand of this apparatus. After 28 days, the specimens were taken from moist room, broken by a testing machine) brand of the machine is also TONI TECHNIK, with ±1% accuracy) in order to determine compressive strength. Rate of load was 2600 N/s. The testing machine has been equipped with platens made of tungsten carbide. These platens had 10 mm thick, 40 mm wide and 40 mm long. A jig was placed between the platens of the machine to transmit the load from machine to the surfaces of the mortar specimen. A lower plate is used in this jig and it can be incorporated in the lower platen. The upper platen receives the load from the upper platen of the machine through an intermediate spherical seating.

Methods

Procedure of the statistical analysis

As previously mentioned, the weight percentage of the cement ingredients and Blaine of the initial materials are the most effective factors on the *CCS* and *IST*. Interaction of these 10 factors also may have significant effect on the targets. Therefore countless combination of factors may effect on the goal parameters. The analysis of variance is a proper way to find out the degree of significance of these factors. For better analysis there is a need to repeat experiments in this analysis to find out experimental errors.

Since the composition and Blaine of the cement raw materials are changed in each experiment, these factors have to be classified in certain levels and the influence of each factor should be investigated in these levels. Therefore each factor is coded as follows and classified into 20 levels: