Development of an Analytical Method for Optimization of High Strength Self-Compacting Concrete Mix Design Containing Fly Ash

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1. Introduction

In the late 20th century a new generation of concrete known as Self-Compacting Concrete (SCC), for the purpose of achieving durable concrete structures, was introduced by researchers. The researchers have been performed various studies to optimize the design mix of self-compacting concrete and the results have been presented in recommendations and methods. Some researchers have presented methods based on some limitations.

In this study, in order to optimize the design mix of self-compacting concrete containing fly ash, a new analytical method was proposed. The proposed method introduces a special relationship between compressive strength and mix design of concrete based on mathematical concepts of optimization and using validated experimental specimens results. The important feature of the proposed method is the relationship between the compressive strength that it introduces as an exponential function with respect to design variables. The exponential relationship of the concrete compressive strength, after constructing the Lagrangian function and study of the Kant-Tuck conditions, the optimization problem can be completely analytical and solvable based on mathematical relations. In other words, use of the computer's methods is not needed. The proposed method is a general approach and is applicable to all types of concretes. In order to introduce this, this method has been used for high strength self-compacting concrete containing fly ash.

2. Optimization model of SCC

The purpose of optimization is minimizing the objective function that it is defined based on design variables, provided that the design constraints had to be satisfied. In this study, the design variables are the weight of components of concrete such as water (x_1), cement (x_2), fly ash (x_3), fine aggregate (x_4), coarse aggregate (x_5), superplasticizer (x_6) and air-entraining admixture (x_7). The objective function is the cost of concrete that it is formulated as follows:

$$\min f(x) = c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6 + c_7x_7 \qquad (1)$$

According to the recommendations of the previous researchers, design constraints have been identified based on the important characteristics of fresh and hardened self-compacting concrete. Thus, each problem has fourteen design constraints. Here, in order to optimization of mix design of the self-compacting concrete based on proposed analytical method, the compressive strength of concrete is one of the main design constraints of the problem which is formulated as Eq. (2):

$$\bar{f}_{cu} = kx_1{}^{\alpha_1}x_2{}^{\alpha_2}x_3{}^{\alpha_3}x_4{}^{\alpha_4}x_5{}^{\alpha_5}x_6{}^{\alpha_6}x_7{}^{\alpha_7} \qquad (2)$$

Where α_1 to α_7 and k are unknown coefficients that they are determined from the processing of experimental specimens results. For this purpose, the results of several experimental studies have been used.

3. Case study

In order to demonstrate the efficiency of the proposed method and validating the results, three numerical examples have been considered for achieving optimal mix design of self-compacting concrete. These examples have the compressive strength of 60, 65 and 70 MPa. The optimization results in Table 1, showed that in the minimum amount of water ($150kg/m^3$), while all of the design constraints are satisfied, the lowest value of the objective function is obtained. The optimization results using the proposed analytical method showed that, this can provide optimal ratios for the mix design of high strength self-compacting concrete containing fly ash, so that in acceptable minimum amounts of water and cement the optimum objective function is obtained.

4. Conclusion

In the optimization process of mix design of the self-compacting concrete using proposed method, the most important design constraints were compressive strength and also the volumetric ratio of water to cementation materials. Also, in the optimal mix design of the high strength self-compacting concrete containing fly ash, the optimum amount of water and cement were obtained, the acceptable minimum amount of them in the construction of self-compacting concrete. In determining the relationship of compressive strength, in order to achieve the desirable and accurate results, the dispersion should be avoided in the reference experimental specimens results.

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Results showed that the construction cost of concrete in the final optimal design with the proposed method, compared to the optimal design of the proposed method using the information of the experimental specimen results, 3.6 percent and compared to optimum design based on the experimental specimen results, 13 percent is decreased, respectively.

Table 1. Results of optimal mix design of the self-compacting concrete with compressive strength of 60, 65 and 70 MPa

Compressive strength (MPa)	Water kg/m^3	Cement kg/m^3	Fly ash kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Super plasticizer kg/m^3	Air-entraining admixture kg/m^3	Cost (Rials)
60	150	350.87	88.6	634.71	959.83	8	0.06	949276
65	150	350.87	88.6	672.27	1016.64	8	0.06	954599
70	150	350.87	88.6	709	1072.23	8	0.06	959808