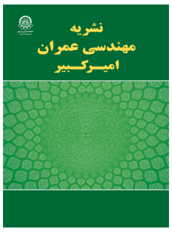

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Determining Optimum Percent of Recycled Coarse Aggregates used in Corrosive Environment Based on Kriging Model

A. Gh. dehvari, M. Miri *, M. R. Sohrabi

Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

ABSTRACT: In this research, have been used of Kriging surrogate methods to obtain the mechanical and durability parameters' estimation models and a very recent meta-heuristic optimization algorithm to obtain the optimum amount of recycled coarse aggregates and cement in the concrete mix to reach an environmentally friendly concrete. Results have shown that the optimum design point in a 70% humidity environment, 3% chloride ion concentration, and a temperature of 23 °C at high corrosion risk level has been reached at 20.33% and 0.40 of recycled coarse aggregate and water-cement ratio, respectively, in single-objective optimization. In addition to this, multi-objective optimization results have shown that in an environment with a 70% humidity environment, 5% chloride ion concentration, and a temperature of 23 °C the optimum design point has been obtained at 18.34%, 0.40 of recycled coarse aggregate, and water-cement ratio, respectively, that the same results hadn't been observed in the single-objective optimization procedure.

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1. Introduction

Recycled aggregates are obtained from the breakage of concrete resulting from the construction waste and can be used as an alternative to natural aggregates in concrete production [1-2]. Recently, the method of electrical resistance of concrete has been applied to assess the risk of corrosion of steel bars in concrete [3]. In this paper, prediction models for compressive strength (CS) and electrical strength (ES) of concrete are defined based on laboratory data with two parameters: water to cement ratio and recycled coarse aggregate based on Kriging theory. These models have been evaluated by the optimization algorithm of ideal gas molecular movement in single-objective and multi-objective modes [4-6] to obtain the optimum amount of recycled coarse aggregates (RCA) and cement consumed in environment-friendly concrete.

2. Methodology

In this study, first, the durability and mechanical parameters of recycled concrete aggregate were obtained from laboratory work. Then, the Kriging method was used to obtain the compressive strength and electrical resistance limit state functions from experimental data obtained based on the Kriging modeling requirement. Finally, these models are used as optimization problem constraints.

3. Result and Discussion

3.1. Experimental results

3.1.1. Compressive strength

Fig. 1 shows, the compressive strength of concrete decreased in maximum water to cement ratio (0.60) by approximately 33.72%, also at a maximum amount of recycled coarse aggregate (100%) it is decreased about 19.97%.

3.1.2. Electrical resistance

As shown in Fig. 2, the electrical resistance of concrete decreased by approximately 40.40% as the maximum percentage of recycled coarse aggregates increased (100%), as well as it is decreased in maximum water to cement ratio (0.60) by approximately 42.79%.

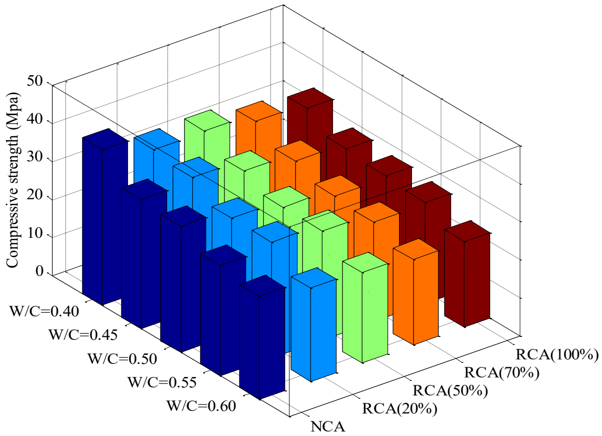


Fig. 1. Compressive strength RCA (%) - W/C relationship.

*Corresponding author's email: mmiri@eng.usb.ac.ir

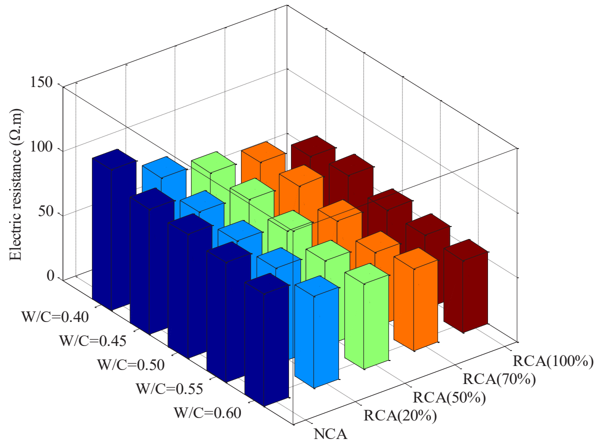


Fig. 2. Electric Resistance RCA (%) - W/C relationship (90 days).

3.2. Modeling Results

In most engineering problems, the main challenge is obtaining limited state functions. Obtaining explicit and precise functions easily applied in the optimization problem often requires a high computational effort. In this study, the Kriging surrogate model was used to obtain the functions of CS and ER. As a model validation requirement, laboratory data were divided into two parts of data used for model building and those used for model evaluation. This division can be performed definitely or randomly using the sampling method without replacement of data coordination index after compilation. Finally, the model with the least error will be selected as the proposed model. These models were employed as the constraints of the optimization problem. Here, Compressive and electrical strength models obtained with the Kriging method are explained as below:

$$f_c = f_{c28}\left(RCA(\%), R_{w/c}\right) \tag{۱}$$

$$\rho = K_{RH}.K_{Cl^-}.K_T.\rho_0\left(RCA(\%), R_{w/c}\right) \tag{۲}$$

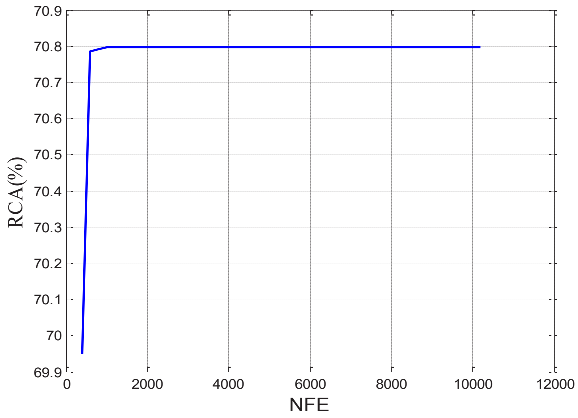
3.3. Optimization Results

In this section, concrete mix with maximum using of recycled coarse aggregates and minimum cement content will be achieved. Therefore, the limit state functions obtained in the previous section are used as constraints of the optimization problem. Hence, the single-objective model of the optimization problem is written as below:

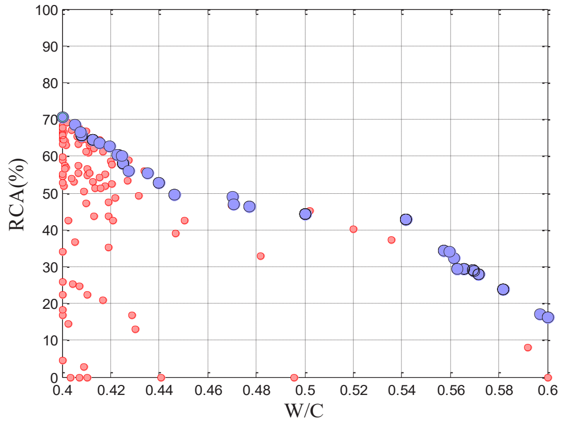
$$\begin{aligned}&Maximize: \quad f(X) = RCA(\%)\\&Subject\,to: \begin{cases} f_{c28}(X_1, X_2) \geq f_{cthr} \\ \rho(X_1, X_2) \geq \rho_{thr} \end{cases} \qquad X_1^L \leq X_1 \leq X_1^U\\&X_2^L \leq X_2 \leq X_2^U\end{aligned} \tag{۳}$$

Multi-objective optimization is also defined as below:

$$\begin{aligned}&Maximize: \begin{cases} \mathrm{f}_1(X) = RCA(\%) \\ \mathrm{f}_2(X) = R_{w/c} \end{cases}\\&Subject\,to: \begin{cases} f_{c28}(X_1, X_2) \geq f_{cthr} \\ \rho(X_1, X_2) \geq \rho_{thr} \end{cases} \qquad X_1^L \leq X_1 \leq X_1^U\\&X_2^L \leq X_2 \leq X_2^U\end{aligned} \tag{۴}$$



(a) Single-objective optimization



(b) Multi-objective optimization

Fig. 3. Optimization result

In this study, $X_1, X_2 = 0 - 100(\%)$ and $f_{cthr} = 25\,\mathrm{MPa}$ were considered. According to the requirement of moderate corrosion risk level, i.e. $\rho_{thr} = 100(\Omega.\mathrm{m})$ and environmental conditions with 70% humidity, temperature 23 °C, and 3% chloride concentration design point with 100% coarse aggregate recycled and water to cement ratio of 0.41 achieved. Also, at a high corrosion risk level, i.e. $\rho_{thr} = 200(\Omega.\mathrm{m})$ and under similar environmental conditions as before, the design point is restricted to the use of 20.33% recycled coarse aggregates at a water to cement ratio of 0.40. Figs. 3(a) and 3(b) show the results of the optimization procedure at medium corrosion risk level with the environmental condition of 80% humidity, temperature 23 °C, and 0% chloride concentration.

4. Conclusions

In general, it has been concluded that the use of recycled coarse aggregates for medium to high corrosion conditions in concrete structures is possible. The possibility of using this type of aggregate at higher corrosive levels and in severe conditions can be made more possible by additives materials such as micro-silica, metakaolin, and fly ash which has a significant effect on the electrical resistance of concrete.

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