Systems engineering method in effective Factors on Compressive Strength of Cement Mortar Using Response Surface

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Abstract— *Cement mortar as a cementitious material is one of the components of concrete, which has a significant effect on the compressive strength of concrete. Therefore, modifying the properties of cement mortar is due to earn the most compressive strength of concrete. The condition of achieving the highest compressive strength is the presence of effective factors on their optimal levels in the mixing plan. In this study, the compressive strength of 18 samples of cement mortar has been studied by statistical optimization method of the response surface affecting by three factors of water to cement material (Binder) ratio at three levels of 0.35, 0.4, and 0.5, fine aggregate to cement material (Binder) at levels 2, 2.5 and Nano-sio$_2$ at levels of 4.5, 9, and 13.5. Results obtained from the response surface method indicate that the water to binder and Nano-sio$_2$ has significant effect on the compressive strength of cement mortar. Additionally, the optimum levels of each factor in order to obtain the highest compressive strength of cement mortar are level of 0.35 for the water to binder, level of 2 for fine aggregate to Binder and level of 13.5 for Nano-sio$_2$. The high statistical accuracy and close proximity to the actual results prove that this statistical method is considered as a reliable method for optimization*.

Keywords—Cement mortar; water to binder; fine aggregate to binder; Nano-sio$_2$; Optimization; Response surface

I. INTRODUCTION

In recent years, the use of concrete as one of the cement base material has increased dramatically [1].Concrete is one the most useful material that human made is generally composed of cement, water and aggregates [2]. Various factors such as water content, amount and type of cement, amount of sand, type of sand, water to cement ratio, aggregate to cement ratio, use of fiber and Nano materials, dimensions, size and shape of aggregate, type of cement materials effects on mechanical and Physical properties of cement mortar [3, 4].Due to the fact that sand contains a large part of the volume of the mortar and is an integral part of the mortar composition, its properties should be thoroughly and accurately examined. A lot of research is taken on the effect of water to cement ratio on properties of concrete particularly the compressive strength of concrete. History of water to cement ratio in the industry and technology of concrete dates back to 1896 when the effect of water to cement ratio on compressive strength of concrete was discovered this year [5] . In addition, the study [6] found that increasing the amount of water reduced the compressive strength of the mortar. Since nanotechnology has a lot of potential and economic effect, the need for research and exploration in this field and its application has increased significantly over the past few decades [7] . Studies have shown that the presence of nanoparticles causes the properties of fresh and hardened material to be modified [8]. We can say that the use of Nano silica in concrete, mortar, and cement causes the mechanical properties dramatically Increase [9, 10] . In addition, the compressive strength and flexural mortars containing Nano-particles are more than mortar without nanoparticles [11].the nanoparticles can be used to produce concrete with high strength properties. In scientific research, in order to achieve the desired goal over time and cost, effective factors should be optimized. When the economy and the quality and time play a key role, it is important to optimize the operating parameters of the process. In concrete industry, optimization is also used in order to find optimal mixing design for all concrete types [12]. The purpose of this study is to determine the optimal mix design of the parameters affecting on cement mortar using response surface method. For this purpose, an experimental work contains 18 mix designs has been done for simultaneous assessment of affecting factors on the mechanical properties of cement mortar. A compressive strength test is taken to determine the effect of each factor. three main control factors used in this study are water to binder ratio at the levels of 0.35, 0.4, 0.5 and fine aggregate to binder at two levels of 2 and 2.5 and Nano-sio$_2$ content at 4.5, 9, and 13.5 levels.

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II. MATERIALS AND SAMPLES

Data and materials used are drawn from research [13] . In this research, ordinary Portland cement (type 425-1) has been used which is in accordance with Iranian national standards 389. Colloidal Nano-sio$_2$ (with a solid content of 30%) was used. The natural washed sand with fineness modulus of 3.2, a specific gravity of 2.74 “g/cm^3”and 1% water absorption with good grading. Fine aggregate grading is considered in accordance with ACI 549R-97 [14] . Water-reducing super plasticizer (naphthalene type with a solid content of 40%) is used to help disperse nanoparticles in a mortar matrix and to achieve good melt performance and workability. The fresh mortar is placed inside a 50 mm oiled cube mold to calculate the compressive strength at the age of 28 days. The mixtures are placed in a mold for 24 hours and then placed in a water reservoir at 20 ° C. the compressive strength is in accordance with ASTM C109-02 standard

III. RESPONSE SURFACE METHOD

The surface response method is one of the DOE (design of experiment) methods that are able to design accurately and is suitable for optimizing multivariate processes that have a relationship between input variables with output variables and effect process response. Central composite design was used to fit second order model and find the relationship between the input variables and the output variable. The basic form of Response Surface methodology is shown in Equation (1).

$$y = f(x_1, x_2 \dots x_n) \qquad (1)$$

Where y is the response variable and ε is the error and noise values for the target function. In order to optimize a mix design, the model of design must model. It is necessary to find an approximation in order to investigate functional relationship between parameters and response. The generic form of Response surface method is shown in Equation (2).

$$y = \beta_0 + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \sum\sum \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

Where ε is the response variable and ε is the error and noise values for the target function. The β coefficient is obtained by least square method. Mathematical relations, statistical methods, regression analysis and optimization are a suitable strategy to solve the problem and close to the optimum response.

IV. LABORATORY DATA

A total of 18 tests for evaluation of parameters on the compressive strength of cement mortar are done. Three factors were selected are fine aggregate to binder ratio (FA / B), water to binder ratio (W / B) and nanoparticles (Nano-sio2). The controlling factors and the level of each parameter are considered. Water to binder ratio is located at three levels of 0.35, 0.4, 0.5 and fine aggregate is in two levels of 2.5, 2.5 and Nano-sio2 are in three levels of 4.5, 9, and 13.5. Table 1 shows the process parameters and their level. Table 2 defines the mixing ratios and the combination based on each level of factors.

V. RESULT AND DISCUSSION

The results of the performance of the response surface method are shown in Table 3. This analysis was performed to the degree of 5% significance and 95% confidence degree. According to Table 3, response surface model is correct and reliable because p- value of the model is less than 0.05. It is also observed that the p-value of water to binder ratio and Nano-sio2 are less than 0.05. Therefore, the water to binder and Nano-sio2 are significant factors on the compressive strength of cement mortar. But the factor FA/B have the p-value greater than 0.05 so this factor doesn’t have significant effect on compressive strength. In general, the following factor that has p-value less than 0.05 is considered as a significant factor in the response [15].

Table 1 - Parameters with their levels

factors	**level**		
	1	***2***	***3***
W/B	0.35	0.4	0.5
FA/B	2	2.5	-
Nano-sio2	4.5	9	13.5

Table 2 - The proportion of mixing samples

Mix number	**W/B**	**FA/B**	**Nano-sio$_2$**
۱	۰,۳۵	۲	۴,۵
۲	۰,۳۵	۲	۹
۳	۰,۳۵	۲	۱۳,۵
۴	۰,۴	۲	۴,۵
۵	۰,۴	۲	۹
۶	۰,۴	۲	۱۳,۵
۷	۰,۵	۲	۴,۵
۸	۰,۵	۲	۹
۹	۰,۵	۲	۱۳,۵
۱۰	۰,۳۵	۲,۵	۴,۵
۱۱	۰,۳۵	۲,۵	۹
۱۲	۰,۳۵	۲,۵	۱۳,۵
۱۳	۰,۴	۲,۵	۴,۵
۱۴	۰,۴	۲,۵	۹
۱۵	۰,۴	۲,۵	۱۳,۵
۱۶	۰,۵	۲,۵	۴,۵

۱۷	۰,۵	۲,۵	۹
۱۸	۰,۵	۲,۵	۱۳,۵

Table 3 – ANOVA table for Response Surface method

	Sum of Squares	**DF**	**Mean Square**	**F-Value**	**p-value Prob > F**	
Model	2501.09	6	416.85	232.22	< 0.0001	**significant**
A-FA/B	26.33	1	26.33	14.67	0.0028	
B-W/B	2265.00	1	2265.00	1261.80	< 0.0001	
C-Nano-sio2	150.44	1	150.44	83.81	< 0.0001	
AB	2.08	1	2.08	1.16	0.3047	
AC	0.92	1	0.92	0.51	0.4893	
BC	31.89	1	31.89	17.77	0.0014	
Residual	19.75	11	1.80			
Cor Total	2520.84	17				

The Contour plot consists of parameters that influence on the compressive strength of cement mortar. This plot can predict the compressive strength of mortars and help to get the most strength in different regions of the area. In Figure 1, vertical and horizontal axes are the amount of Nano-sio2 and the FA/B. The different colors of the response represent the power of the response. The darker the color, the greater will be the compressive strength [16]. As we can see, there is no change in the horizontal motion in the graph with the stagnation of the vertical factor. It can be seen that FA/B has the partial effect on compressive strength of cement mortar. But by vertical movement in the diagram, we clearly see changes in compressive strength. The compressive strength increased by increasing the level of Nano-sio2.

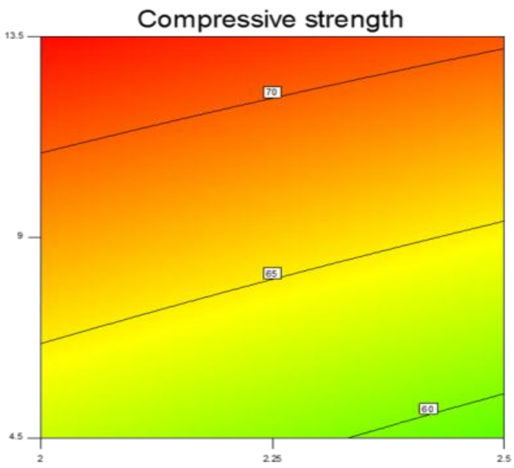

Fig. 1. Contour plot of FA/B and Nano-sio$_2$ materials for compressive strength of cement mortar

Fig. 2 is the desirability plot for compressive strength of cement mortar which is based on the different levels of effective parameters. Desirability changes have been increased by decreasing the proportion of W/B and increasing the amount of Nano-sio2 respectively. The value of 0.993 indicates the high accuracy of the test and the method. Therefore, if the W/B ratio is 0.35 and the Nano-sio2 content is 13.5, the conditions for achieving the highest compressive strength of mortar are very favorable and the goal occurs in this conditions. The effect of three factors and optimal values of these ratios can be seen in Figure 3. Accordingly, in order to obtain the highest compressive strength, the optimal level of W/B is 0.35, the optimum level of the FA/B is 2 and the desired level of Nano-sio2 is 13.5. If the mortar with these proportions is mixed, the model predicts that a mortar with a compressive strength of 73.04 will be obtained and the model's desirability for achieving this value is 0.993. In order to verify the accuracy of the response surface method, the configuration tests are performed in optimal conditions. Figure 4 compares the actual and predicted compressive strength of cement mortar. In this plot, the horizontal axis is the actual values and the vertical axis is predicted value which represents by Response Surface model. The difference between the actual and predicted compressive strength of cement mortar is very low which regression plot also confirms these results. The closer the test data points are to the line, the accuracy of the model is high in prediction and the results are reliable. If the value is close to 100 %, the output results are close to reality [16]. R-square (R^2) were used as the criteria between the experimental and predicted values, according to the Equation (3). The R-square value of the model is 99.21 % which shows high accuracy in order to predict the compressive strength of the cement mortar. Normal Plot of Residual can be used to examine the output results. This plot examines the normalization of the data. According to Figure 5, points are close to the normal line of the plot. The closer these points to the best passing line, the normalization of the test data.so the data is almost normal and the distribution is desirable and uniform. Therefore, it can be concluded that the response surface method is a very useful method for predicting the compressive strength of cement mortar.

$$R^2 = [n\,(\sum t_i o_i - \sum t_i \sum o_i)^2] \div [(n \sum t_i^2 - (\sum t_i)^2)(n \sum o_i^2 - (\sum oi)^2)] \qquad (3)$$

Where t is the experimental value, o is the predicted value, and n is total number of data.

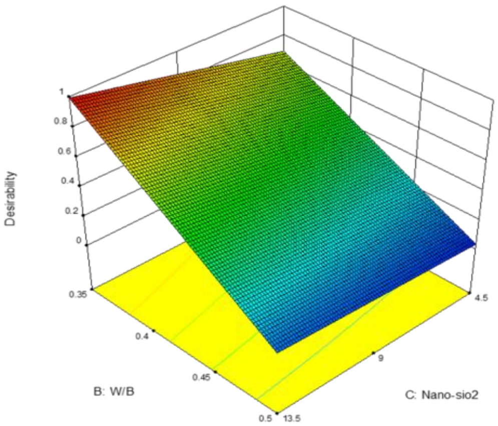

Fig. 2. Desirability plot of W/B and Nano-sio$_2$ materials for compressive strength of cement mortar

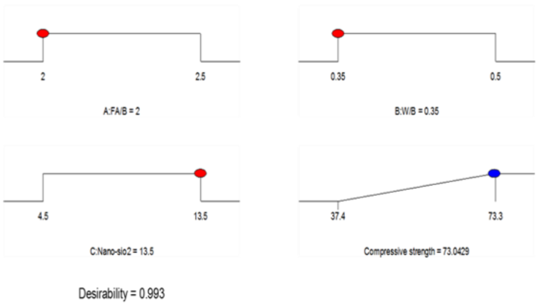

Fig. 3. Optimum points of each factor provided by the response surface model

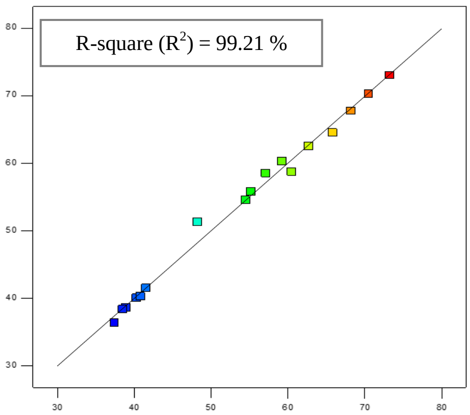

Fig. 4. Regression plot of Response Surface model for compressive strength of cement mortar

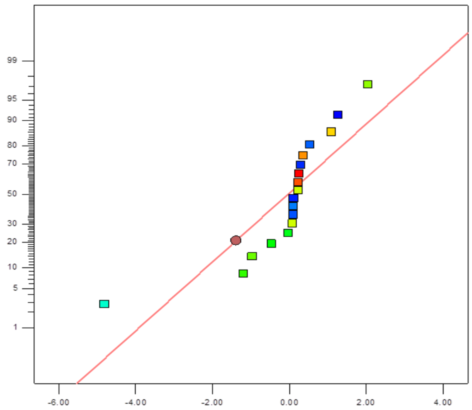

Fig. 5. Residual normal plot of Response Surface model for compressive strength of cement mortar

VI. Conclusion

According to the ANOVA table, parameters W/B and Nano-sio2 are the most effective factors on the compressive strength of the mortar, but the fine aggregate to binder has no significant effect on the compressive strength of cement mortar. The response surface methodology provides the optimal level of each factor. Accordingly, the optimal values for the W/B, FA/B and the amount of Nano-sio2 are 0.35, 2 and 13.5 respectively. As the ratio of W/B decreases and the amount of Nano-sio2 increases, the compressive strength of cement mortar increases. Based on response surface plots, the highest compressive strength occurs at the lowest W/B ratio and the highest amount of Nano-sio2. The gradient of these factors in the plot shows the significant effect of this factor on compressive strength of cement mortar. If the factors are at their optimal levels, the predicted compressive strength is reported to be 73.04 by response surface method. The R-square value of the model is 99.21 % which shows high accuracy in order to predict the compressive strength of the cement mortar Therefore, it can be concluded that the response surface is a reliable method for optimization and predicting.

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