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Optimizing Compressive Strength of Micro- and Nano-silica Concrete by Statistical Method

Mahsa Zarehparvar-Shoja [a], Hamid Eskandari-Naddaf [b*]

[a] *BS student, Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran.*

[b] *Associate professor Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran.*

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Abstract

In recent years, the use of nano-particles to improve the properties of concrete has created a new perspective on concrete technology. Studies in this field indicate improved concrete properties and higher strength by adding nano and micro silica particles to concrete mixes. In this regard, 12 mixing designs with different amounts of these admixtures with three types of cement strength classes (525,425,325) and 36 cubic samples (10 × 10 × 10) were designed and tested to measure compressive strength, of which we have only used 6 mixing plans in this research. The purpose of this research is to present a new method for concrete mix design by optimizing principles. Therefore, in this paper, the Taguchi statistical methods and the factorial design of the optimal mixing plan for this type of concrete are used to reduce the number of experiments to predict the optimal composition of the materials. The results obtained from the MINITAB software show that the effect of combined micro-silica and nano-silica on the compressive strength is in one direction and the effect of these two factors is more than cement strength grade of the cement and also the optimal value for micro-silica and nano-silica are estimated to have an optimum amount of micro-silica and nano-silica of 95 and 38 grams, respectively.

Keywords: HLLC Scheme; Factorial Design; Taguchi Method; Compressive Strength; Nano-Silica; Micro-Silica.

1. Introduction

In order to produce a concrete with a particular compressive strength, various factors such as the amount of combinatorial components and its related admixture , as well as the amount and time of rotation of the mixing machine in each step, should be carefully considered [1-4]. Changes in each of these factors alter the condition of the concrete. One of the important factors is the rate of admixture in concrete, which we are referring to as micro-silica and nano-silica [5]. Due to the effects of using Nano-silica in concrete, including improving microstructures, reducing permeability, reducing porosity and increasing compressive strength it can be concluded that the use of nano-silica is valuable that Collapardi et al. confirm this [6]. In recent years, the use of nano-silica to improve the properties of concrete has created a broad perspective on concrete technology [7]. Nano-particles have shown special properties in concrete mix design due to their very small particle size and their high surface area [8]. Nano-materials, including silica nano-particles, carbon nano-tubes [9], iron nano-particles [10], aluminum nano-particles [11] and nano-montmorillonite [12], have been tested to improve the properties of concrete including nano-silica particles due to their high pozzolan properties [8]. Jo et al. (2007) have shown in their experiments that the increase in compressive strength for mortars containing nano-silica is 3 to 12 percent [13]. T.Ji (2005) has shown that the permeability of concretes containing nano-silica decreases [14]. The use of nano-silica in high-strength concrete can increase short-term and long-term strength.

* Corresponding author: hamidsttu@yahoo.com

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Adding a small amount of 25 percent of nano-silica results in an increase in compressive strength by 10 percent and an increase in flexural strength by 25 percent [15]. Also, the use of nano-silica in cement or concrete, even in small amounts, can significantly improve the mechanical properties of cement materials [16]. Also Nazari and Riahi showed that 70 percent improvement in compressive strength of concrete can be obtained by adding 4 percent of nano-silica [17]. Another of these admixtures that we discuss in this paper is micro-silica, and the change in each rate of micro- and nano-silica concentrations affects the compressive strength of concrete. Micro-silica has many advantages, including high initial compressive strength, longer lifetime, increased resistance against of abrasion, high electrical resistance and low permeability, so a lot of research has been done on micro- and nano-silica. Micro-silica is one of the materials that have been seriously considered by civil engineers for using in concrete in the last decade. Due to the specific characteristics of pozzolanic micro-silica, its use to improve mechanical properties and increase the durability of concrete in advanced countries is increasing [18]. One of the features of micro-silica that improves the properties of fresh and hard concrete is the smoothness of its particles. The micro-silica particles, which are approximately 100 times as smooth as cement, fill the pores between cement in concrete, which increases the strength of the concrete and reduces its permeability [19, 20]. The maximum compressive strength was related to concrete with 10 per cent of cement replacement by micro-silica [21]. High-performance concrete containing micro-silica is used in highway bridges, parking decks, marine structures and pavement decks, and in repair of various cement products [22].

Nili et al., expressed that the highest compressive strength of concrete at the age of 7 and 28 days, were obtained from a mixture of 6-per-cent micro-silica and 7-per-cent nano-silica [23]. Sohrabi and Karbalaei conducted an experimental study on compressive strength of concrete containing cemented rubber and micro-silica with a water-cement ratio of 0.5 and they found out that increased micro-silica increases compressive strength and they cited its reason filling nano-metric cavities in the cement paste and dandifying the structure [24]. Guneyisi et al. Also conducted a study on concrete containing rubber and micro-silica, and reported an increase in compressive strength with an increase in micro-silica, and also attributed this increase to filling the micro-silica cavities [25]. Sobolev studied the high-performance concrete compressive strength and found out that maximum compressive strength was 91mega-Pascal in 15 percent micro-silica [26]. Micro-silica originally became a cement substitute, but at the moment the most important reason for using it is the production of high-performance concrete. But the research has shown that the effect of nano-silica on compressive strength is higher than micro-silica. Qing et al. (2007) have shown that nano-silica has higher pozzolanic properties than micro-silica and increases the compressive strength [27]. Adding 10 percent of nano-silica increases the compressive strength of concrete by 26 percent, while the same amount of micro-silica increases the compressive strength of concrete by 15 percent [8]. Due to the high importance of micro- and nano-silica on the compressive strength of concrete, it can be use optimization, finite element and statistical methods [28-30].

In this study Taguchi method and factorials to give us the optimal amount of each of these additives. S. Bhanjaa, B., and B. Sengupta, using the regression math model, improved the statistical models to predict the 28-day compressive strength of concrete containing nano-particles with a water-cement ratio of 0.3 to 0.42 and 5 to 30 per cent of nano-particles. Based on laboratory results obtained from regression analysis, a model was developed for optimizing and predicting the compressive strength of concrete containing nano-particles [31]. In late 1940, Dr. Taguchi introduced new statistical concepts and later proved that these concepts were valuable tools in quality control and improvement [32]. Since then, many Japanese industrialists have used this method to improve product and process quality. Taguchi's method is quite different from conventional engineering methods [33]. Taguchi's methodology emphasizes on designing quality when designing products and processes, while commonly used methods are based on inspection and quality control during- or post-production process [34]. In the laboratory program, the kinematic method of designing Taguchi experiments was used to construct samples and determine the optimal amount of materials. One of the main advantages of this method, in addition to lowering costs and increasing speed, is that optimal conditions are chosen that the effects of uncontrollable factors cause minimal changes in system performance and the quality of output products [35-37]. Taguchi experiments are one of the statistical methods that, while maintaining the accuracy and accuracy of the results, can significantly reduce the number of experiments, and this method is able to optimize the process, production, or the desired conditions, Depending on the variables examined, even if they are not available in the experiments. In this study we used factorial method in addition to Taguchi method. The factorial design method is used to evaluate two or more factors simultaneously and the factorial method is an efficient method and it’s advantage is determining the interaction between factors. We used Taguchi statistical methods and factorial for the simultaneous effect of micro-silicon and nano-silica, and we observed that in nano-silica 38g and micro-silica 95gr with cement grade325, we have the highest compressive strength; however, these values were modified by increasing the resistance grade of cement.

2. Materials and Methods

In this research, were used three types of resistance grade of Portland cement: 1-325, 1-425 and 1-525. In order to manufacture samples, fine aggregate silica and gravel were used according to the grain size curve ASTM Code for the application of aggregates in concrete. It should be noted that the percentage of fine-grained was 50per cent compared to fine-grained and coarse aggregate. Silica fume was used as powder and in gray, which was added during the mixing process. Multipurpose additive increases durability, strength and density and as well as concrete to anti-sulfate and reduces permeability. Nano-silica, used as a colorless liquid, is a super-pozzolanic based on nano-technology with a very impressive effect and low consumption. Polymer fibers (polypropylene) are used as secondary reinforcement of concrete or mortar to reduce shrinkage and cracking control and increase the durability of concrete in the long run. The fibers are added to the mixed dry or fresh mixture in accordance with the manufacturer's instructions at the time of construction and mixing of concrete with other materials. The consumption varies from 0.5 to 2 kg per cubic meter depending on expected performance. Another way is to mix the fibers in water before adding it to the dry mix. In these experiments, the fibers were mixed according to the first method. Polycarboxylate-based super-lubricant (PCE) was also used and 0.2 to 1.2per cent cement weight was added to the material (depending on the slump). In this research, three types of resistance grades of Portland cement type 1-325 (from Sabzevar cement factory) and 1-425 (from Sabzevar cement factory) and 1-525 (from Zave Torbat Heydarieh factory) were used.

In this research, laboratory specimens were constructed in cylinders of $10 \times 15\ cm$ and a cube of $10 \times 10\ cm$ to determine the compressive strength in 12 mixing designs and cements in 3 categories of resistance. In total, the number of samples reached 36 cylinders and 36 cubes. The mixing plan for the composite concrete sample by weight is given in Table 1. It should be noted that, as shown in the mixing table, mixing plan 1 is without fibers or additives. Mixing plan 2 to 6 is with fiber and water-cement ratio 0.5 and mixing plan of 7 to 12 with micro-silica and nano-silica and water to cement ratio 0.4 were constructed. In the second six studies, the combined effect of micro-silica and nano-silica in the compression strength of concrete was considered. The total amount of micro-silica and nano-silica is 10per cent of the weight of cement, and this amount is the same in all relevant mix designs (7 to 12), and their difference is in the use of a mixture with different amounts of micro-silica and nano-silica. Because the reinforcement is placed exactly in the middle of the cylindrical sample and the test is done in high precision, wooden pieces with a hole in the diameter of the reinforcement are ued so that concreting is made through the side vents of the wood. Also, the exact length of the fitting of the reinforcement in the concrete (buried length) is already specified in different colors to give the test results a precision. The treatment of the samples is also carried out in a water tank with suitable temperature and humidity conditions. at first, cube samples were tested to obtain compressive strength and the results of 36 samples were extracted and recorded. In order to determine the compressive strength, cube samples of $10 \times 10 \times 10\ cm$ (for age 28 days) are made. For all cubic samples, treatment is carried out under flood conditions. For this purpose, after pouring concrete into pre-prepared molds, the molds were kept for a period of 24 hours at a constant temperature and humidity, and after that time, hardened samples were placed in a water pond with a temperature of 20 °C. Concrete samples are taken out of the water after the necessary time (28 days), and after two hours of drying, they are placed below the compressive strength measuring device.

Figure 1. Many of compressive specimens

Table 1. Concrete Mixing Design

Plan number	Super Plasticizer (gr)	Fibers (gr)	nano-silica(gr)	Micro-silica (gr)	Cement (gr)	Water (gr)	Aggregate (gr)
1	18	0	0	0	1330	665	3600
2	18	6	0	0	1330	665	3600
3	18	12	0	0	1330	665	3600
4	18	18	0	0	1330	665	3600
5	18	24	0	0	1330	665	3600
6	18	30	0	0	1330	665	3600
7	19	0	0	133	1197	532	3600
8	19	0	38	95	1197	532	3600
9	19	0	95	38	1197	532	3600
10	19	0	66.5	66.5	1197	532	3600
11	19	0	19	114	1197	532	3600
12	19	0	133	0	1197	532	3600

3. Statistical Method (Research Methodology)

The next step is to define an objective for a performance measure of the process. In this study maximum compressive strength mechanical of concrete are considered. The objective is maximizing strength of concrete. Then, the design parameters affecting the performance measure is assigned. Parameters are variables within the process that affect the measure. Three parameters were selected: micro-silica, nano-silica and resistance class of cement. In this research seven levels are used. Increasing the number of levels leads to a large number of experiments. Next step is creating orthogonal arrays for the design parameters indicating the number of parameters and conditions for each experiment. By determining number of parameters and levels, the proper orthogonal array can be selected. Then, the experiments indicated in the completed array to collect data on the effect of the performance measure are carried out. Finally, the effect of each parameter using signal-to-noise ratio is evaluated. The Taguchi method has been generally adopted to optimize the design parameters because this systematic approach can significantly minimize the overall experimental costs. In this research, three variables with seven levels are applied which results in 2187 combinations. This method uses a special design of orthogonal arrays to determine the optimum experimental conditions. Signal-to-Noise ratios (S/N), serve as objective functions for optimization, help in data analysis. In Taguchi designs, a criterion is used to determine control factors which decreases variability in a process by minimizing the effects of uncontrollable factors. While control factors are those design parameters that can be controlled, noise factors cannot be controlled during production. Noise factors can be controlled during experimentation. In the design of experiment by Taguchi method, noise factors are manipulated to provide variability through setting of optimal control factors. The higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors.

3.1. Taguchi Analysis

The Taguchi experimental design method was introduced in 1960 by Professor Taguchi. This method can determine the optimal conditions with a minimum number of tests and reduce the time and cost of performing the required tests [38]. Taguchi proposed experiments including the use of orthogonal arrays in organizing the influence of process parameters and surfaces that need to be changed. This method allows the study of factors that have the greatest impact on product quality with the least number of experiments. The loss function is determined to calculate the deviation between the laboratory value and the required value, and the loss function is converted to signal-to-noise or S/N ratio. Typically, depending on the types of specification, there are three types of S/N ratios: the lower - the better, (LB) the higher - the better (HB) the nominal - the better (NB). The S/N ratio for each attribute is calculated according to the following formula:

Larger is better: This attribute is used when the goal is to maximize the output.

$$S/N = -10 \times log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right) \tag{1}$$

Smaller is better: This attribute is used when the goal is to minimize the output.

$$S/N = -10 \times log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}Y_i^2\right) \tag{2}$$

Nominal is better: The goal is to achieve the average amount of output.

$$S/N = -10 \times log_{10}\left(\frac{1}{n}\sum(y_i - y_0)^2\right) \quad (3)$$

Where, n is the number of repetitions and y is the measured output.

Micro-silica and Nano-silica were considered as control factors to optimize compressive strength. The signal-to-noise ratio in a simple definition is the ratio of the average (signal) to the standard deviation (noise), which is the inverse of the coefficient of alterations of the process response, and it shows the rate of variation of the response, which is the result of repetition of the tests [39]. Given the fact that the S/N ratio is proportional to the inverse of the coefficient of variation, this increase leads to a reduction in variations. Considering the purpose is landing maximal compressive strength, in this study the criterion the higher-the better (HB) for assessing was chosen.

3.2. Factorial Design

The factorial design is usually used for very precise studies, and it is used when the number of variables is limited [40]. In the design method of the factorial experiment, the effects of all experimental variables, factors and interactions on the responses are examined. In order to investigate the effects of k variables in the design of the experimental factorial design, 2k test is needed, after which the main effects and also all interactions effects can be fulfilled, and it is clear that the number of experiments increases linearly with increasing variables.

The experimental design method is used to compare experimental results. In this method, the design of the laboratory is determined once and the experiment is carried out, and the specified value of the performance of each test is used to analyze the relative effects of each parameter. In this factorial design, three factors are evaluated simultaneously and their interaction is found [41].

3.3. Analysis of Variance (ANOVA)

In Table 2 and 3, two variances analyses are shown for fitting equations. The following table shows the function of the factorial design. The ANOVA results show that the equations show sufficient correlation and the change between the response and significant variables. This design is generally used to fit a second-order model that is hand-crafted using regression.

$$R\% = \beta_0 + \sum_{i=1}^{n}\beta_i x_i + (\sum_{i=1}^{n}\beta_i x_i)^2 + (\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\beta_{ij}x_i x_j) \quad (4)$$

Where β_0 is a constant and β_i is the slope, or the linear effect of the input of the factor X_i, and the linear β_ (ij) is represented by the linear effect between the input of the factor X_i and X_j [42].

The p-value is used to analyze the variance table to determine whether the effects are statistically significant in the model. For using p-value, the value of p-value must be determined for the effect needed to evaluate and compare the value of p-value with the α-level and generally α-level = 0.5 is used. If p-value is less than or equal to α-level, it will be concluded that the effect is significant. The analysis of variance for compressive strength in Table 1 and 2 is as follows:

The value of p-value for a set of interactions on both tables is equal to 0.178, which is larger than α-level of 0.05, so there is a significant interaction and the effect of each factor is dependent on the level of each factor. The model consists of three main effects, and the value of p-value for the set of main effects is 0.005, which is less than α-level = 0.05. The value of p-value for micro- and nano-silica is p-value = 0.008 for cement resistance class is 0.023 and all three factors are effective and have a significant effect on compressive strength, but micro- and nano-silica are more important for compressive strength.

Table 2. Analysis of Variance for compressive strength of cement vs micro silica

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	577.59	616.45	308.22	8.12	0.005
Micro-silica	1	369.26	369.26	369.26	9.72	0.008
Cement strength class	1	208.33	247.19	247.19	6.51	0.023
2-way intractions	1	76.47	76.47	76.47	2.01	0.178
Micro-silica *cement strenght class	1	76.47	76.47	76.47	2.01	0.178
Residual Error	14	531.71	531.71	37.98	-	-
Total	17	1185.78	-	-	-	-

Table 3. Analysis of Variance for compressive strength of cement vs nano silica

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	577.59	616.45	308.22	8.12	0.005
Nano-silica	1	369.26	369.26	369.26	9.72	0.008
Cement strength class	1	208.33	247.19	247.19	6.51	0.023
2-way interactions	1	76.47	76.47	76.47	2.01	0.178
Nano-silica *cement strength class	1	76.47	76.47	76.47	2.01	0.178
Residual Error	14	531.71	531.71	37.98	-	-
Total	17	1185.78	-	-	-	-

4. Results and Discussion

The main effect plot is used to compare the relative strength of the effects against other factors [43]. Each of these graphs can determine which factors have a significant effect on any of the qualitative characteristics. The graph [2] for compressive strength of concrete is drawn for three grades of cement (325, 425 and 525) separately. The highest S / N ratio given in the graph provides us the optimal value of each of the given parameters [44]. From Figure 2a and 2b and 2c, it is concluded that the highest compressive strength is obtained with the amount of nano-silica (38 g) and the amount of micro-silica (95 g). As we study the two-factor slopes, the changes in micro- and nano-silica on the compressive strength are the same, so their effect is the same. As shown in Table 2 and 3 micro- and nano-silica have a significant effect on compressive strength because the value of p-value is less than α-level = 0.05. So the best combination for concrete with high compressive strength is micro-silica (95 g) and nano-silica (38 g). In diagram 3c, the resistance grade of cement 525 has the lowest S / N value and therefore, has the lowest compressive strength. And from analyzing gradient of the three graphs we find out that the effect of micro- and nano-silica is more significant than the effect of resistance grade of cement. Using Portland cement reduces concrete performance, but improves compressive strength, tensile strength, and modulus, and also, adding Portland cement decreases absorption of water and porosity [45]. From Chart 3 it can be concluded that the best combination for concrete with high strength is micro-silica (95 g) and nano-silica (38 g) and resistance grade of cement (325).

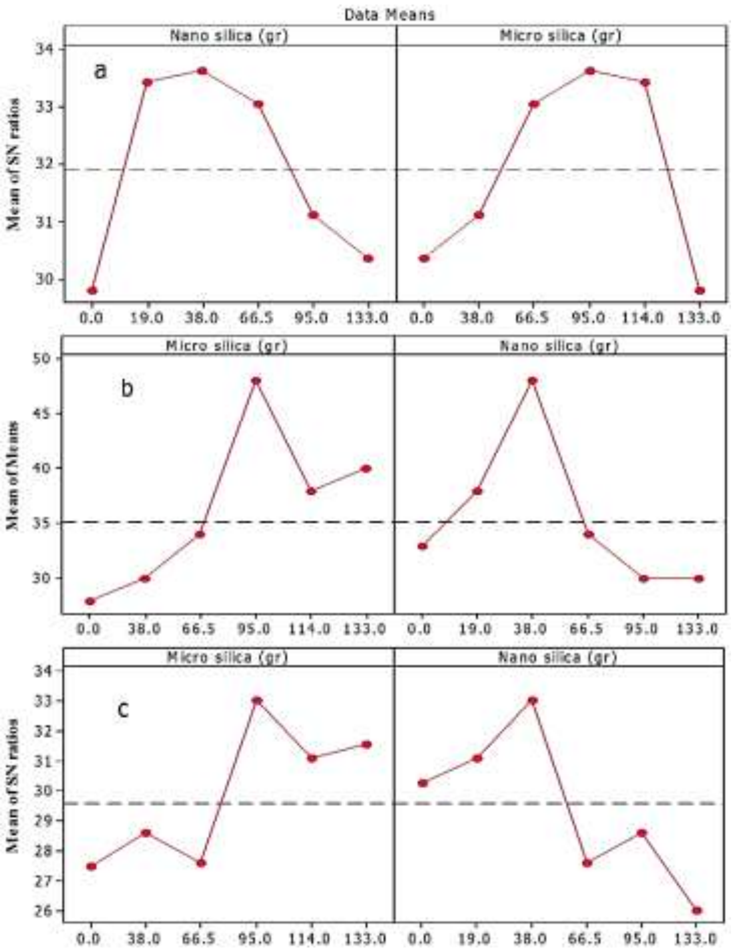

Figure 2. Main effect plot S/N ratios compressive strength ((a) cement 325; (b) cement 425; (c) cement 525)

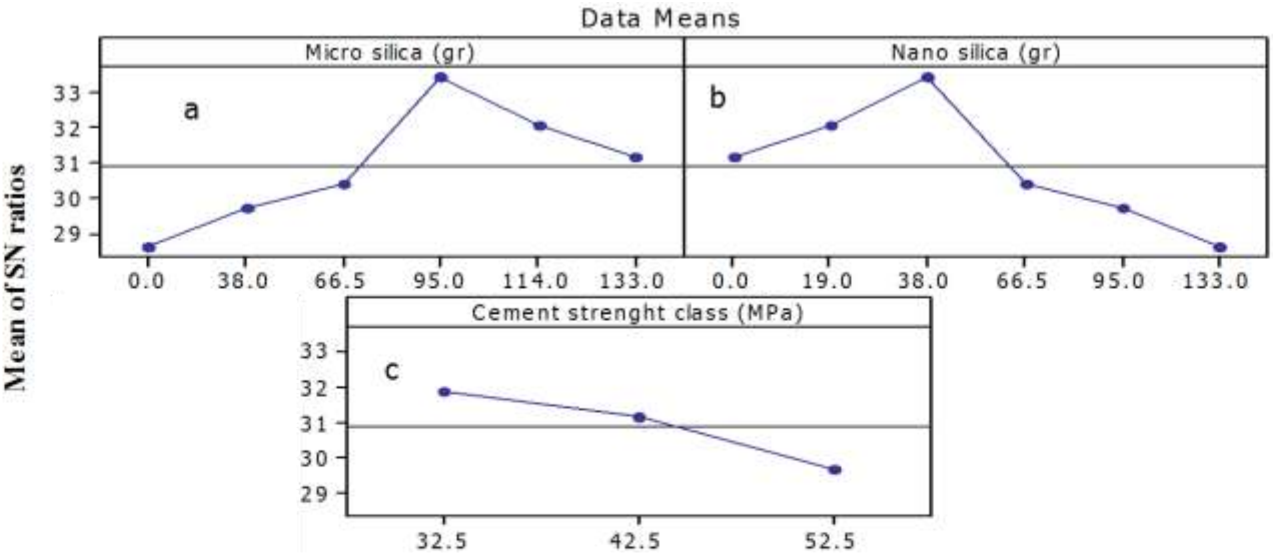

Figure 3. Main effect of S/N ratio

Figure 4 shows the relationship between the response and the variables. The contour graph is useful to find the optimal output value. The contour graph shows the strengths and weaknesses of each model and helps to select the optimized combination scheme for the target [45, 46].

From Figure 4a it is also concluded that by using Portland cement 325, compressive strength is optimized when the micro-silica is in the range of 95- 114 g and the nano-silica is in the range of 19-38 g. From Figures 4b and 4c we also conclude what the resistance grade of the cement is heightened, the effect of the micro-silica and the nano-silica is lesser than and in the lesser range of micro- and nano-silica, increasing compressive strength is observed. In the study of the simultaneous effects of micro- and nano-silica with resistance grade of cement, we conclude that the resistance class of cement 525 reduces the range of effect of micro-silica and nano-silica.

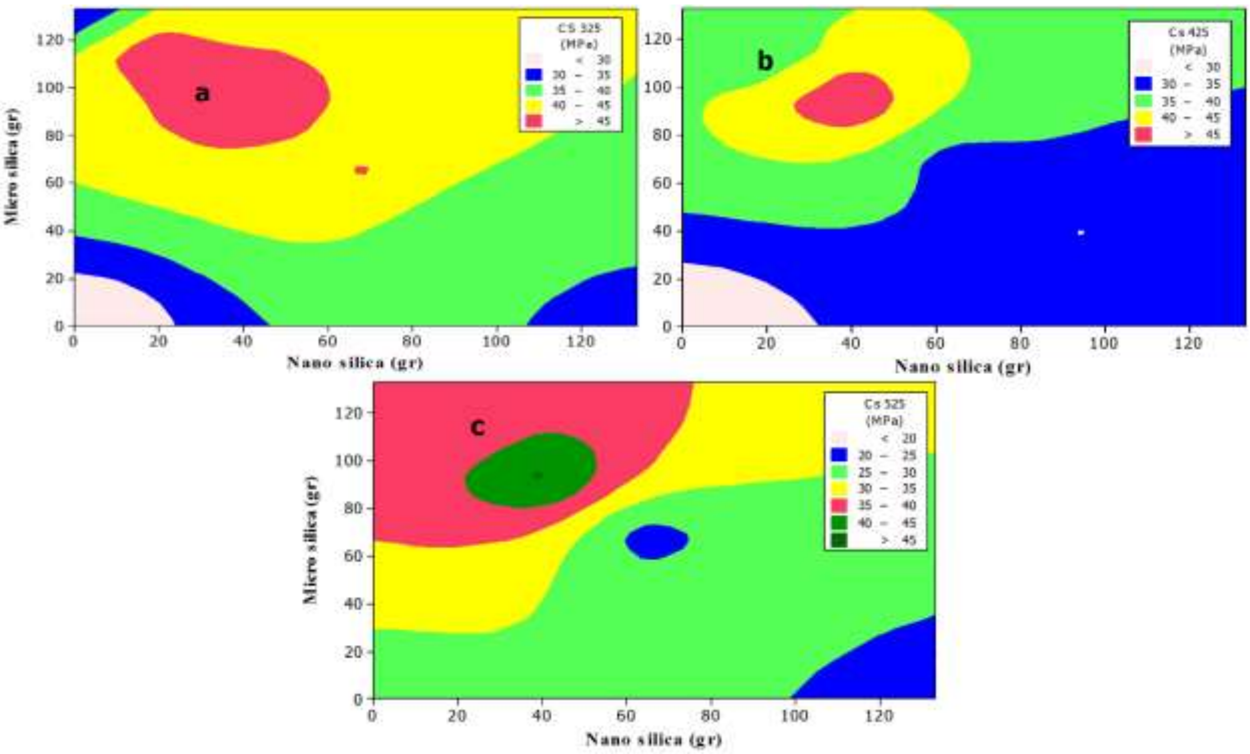

Figure 4. Contour plot Of compressive strength, (a) Cement 325 vs nano-silica, micro-silica; (b) Contour Plote cement 425 vs nano-silica , micro-silica; (c) Cement 525 vs nano-silica , micro-silica

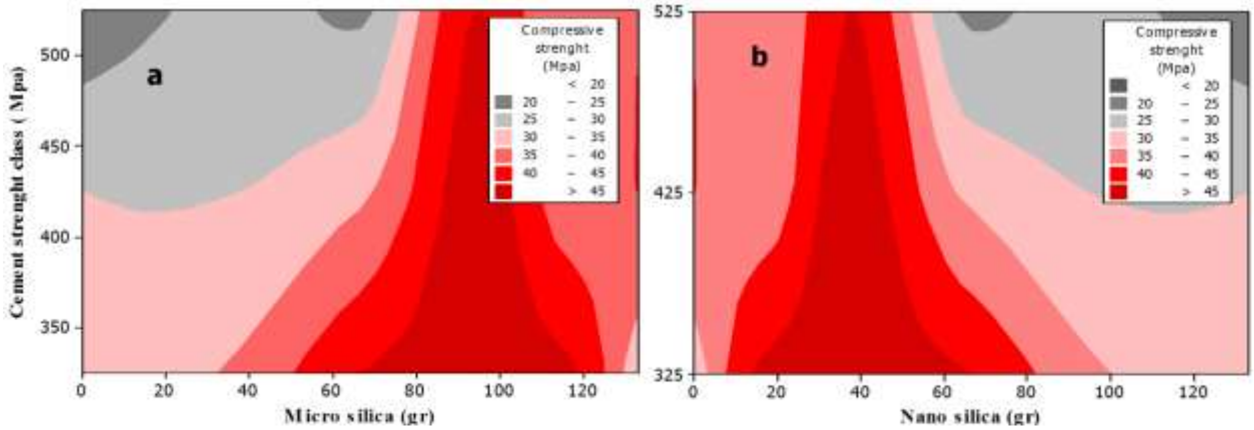

Figure 5. Contour plot Of compressive strength ((a) Compressive strength vs compressive cement class, micro-silica; (b) Compressive strength vs compressive cement class, nano-silica

If we want to look at the impact of two variables on the compressive strength simultaneously in Fig 5a, we see that at the point where micro-silica increases, that is, in the range (114-66.5 g), and in all of our cement resistance points, we have the highest compressive strength. Micro-silica is used due to the increased strength and durability of concrete, which nowadays, with the use of micro-silica and super lubricants, achieve high resistance of 100 MPa with ordinary materials [47]. Figure 5b shows that nano-silica is almost in the range of (19.66 to 19.0 gm) and in all cements strength points, the highest compressive strength is observed. According to the results of previous studies, the flexural strength and compressive strength of concrete by adding nano-silica is higher than that of conventional concrete. If by increasing the ratio of nano-silica , the compressive strength of 28 days increases and that the nano-silica as a filler fills cement holes, such silica foam increases concrete strength [48]. From Figure 4, we conclude that by using Portland cement 325, compressive strength is optimized when the micro-silica is in the range of 95- 114 g and the nano-silica are in the range of 19-38 g. From Figures 4b and 4c we also conclude that the higher the resistance grade of the cement, the less the effect of micro- and nano-silica, and in the lower range of micro- and nano-silica, increasing compressive strength is observed. In the study of the synergistic effects of micro- and nano-silica with resistance grade of cement, the resistance class of cement 525 reduces the range of effect of micro- and nano-silica.

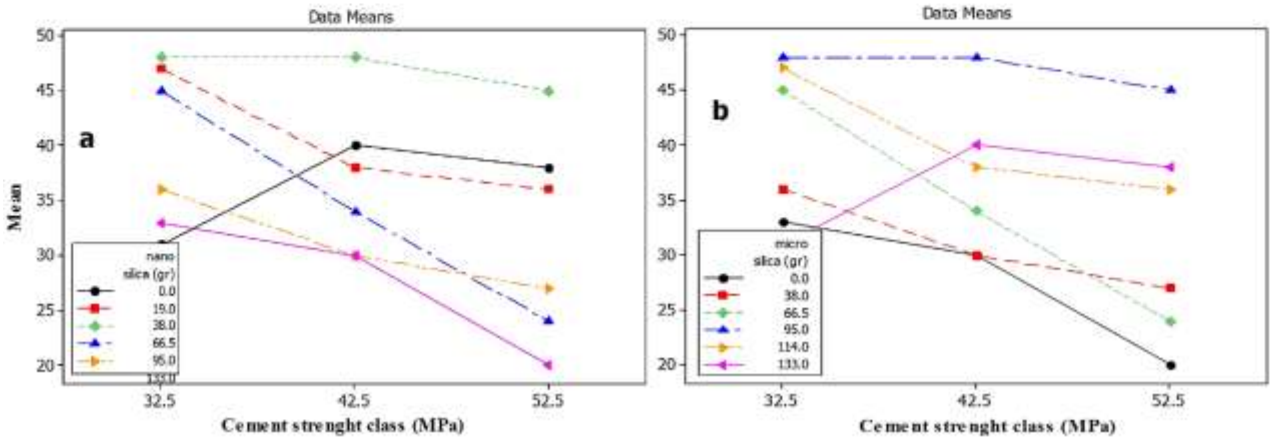

Figure 6. Plot for compressive strength cement ((a) Interaction for compressive – nano-silica; (b) Interaction for compressive – micro-silica

The interaction charts are used to interpret the meaningful interaction between process parameters [48]. According to the diagram, by using nano-silicon, the compressive strength in the cement category 425 reaches its maximum value. At the surface of the nano-silica, we have the highest compressive strength of 38 grams, but the impact of the cement resistance class on the compressive strength is negligible. For the same line, 38 grams of nano-silica is almost horizontal, but in the amount of 38 g of nano-silica and 325 cement grade, we have the highest compressive strength. Nano-silica is 66.5 grams the most effective factor in compressive strength because its slope is higher than that of other nano-silica. Recent studies show that adding nano-silica can significantly improve mechanical and physical properties and durability of concrete structures [49, 50]. As shown in Table 2, there is a significant interaction between nano-silica and cement resistance classes and the value of p-value for a set of interactions is 0.178. Chart 6b shows the interaction of cement resistive micro-silica. In this graph, we find out that the 95 grams of micro-silica and the 325 cement resistance grade have the highest compressive strength. At 66.5 grams in micro-silica, due to the slope, the most effective level is between the other levels.

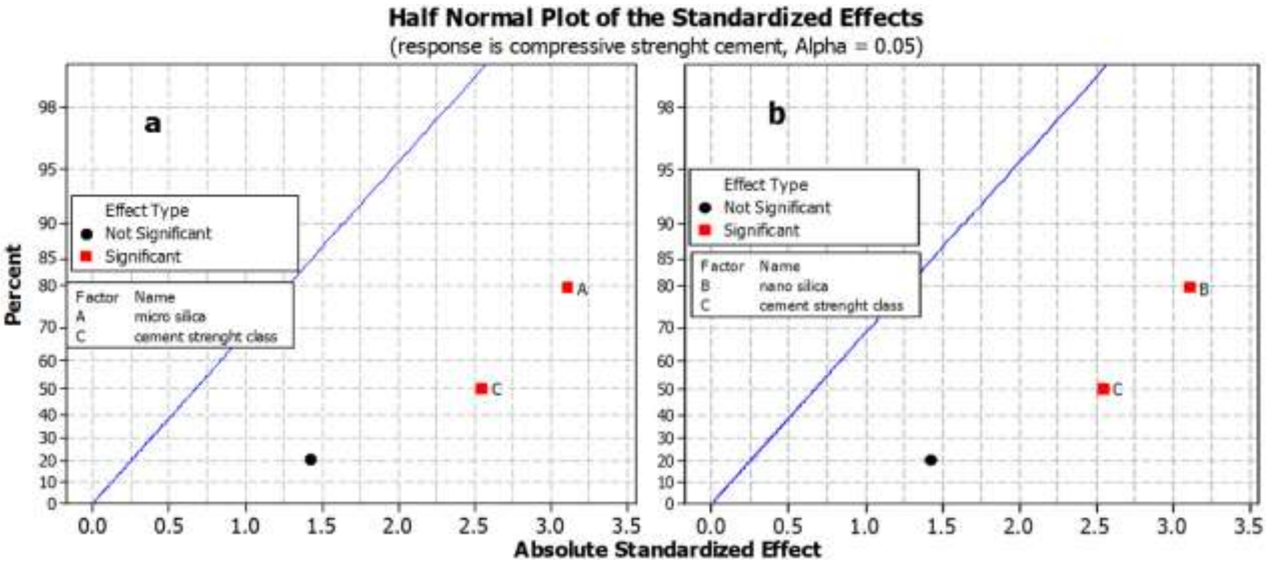

Figure 7. Half Normal Plot of the Standardized Effects

Use the Normal Plot Half charts to compare the relative value and the statistical significance of the original effect and interaction, and they determine the magnitude and importance of an effect. From Diagram 7a, we understand that the effect of A, C is statistically significant to AC. Therefore, AC should not be considered for empirical relationships because the AC point is near the distribution line, so the microfiltration factors and cement resistance class have a great influence on compressive strength. Micro-silica in concrete has many benefits, including the reduction of cracks caused by cement hydration, better durability against sulfate attack and high resistance. In Figure 7b, nano-silica is the most effective factor, and after that, the cement resistance category is a significant factor. Li's research showed that when the silica nano-particles are added to the mixture in a small amount, the compressive and flexural strength as well as the abrasion resistance of the mitochondria increases [51].

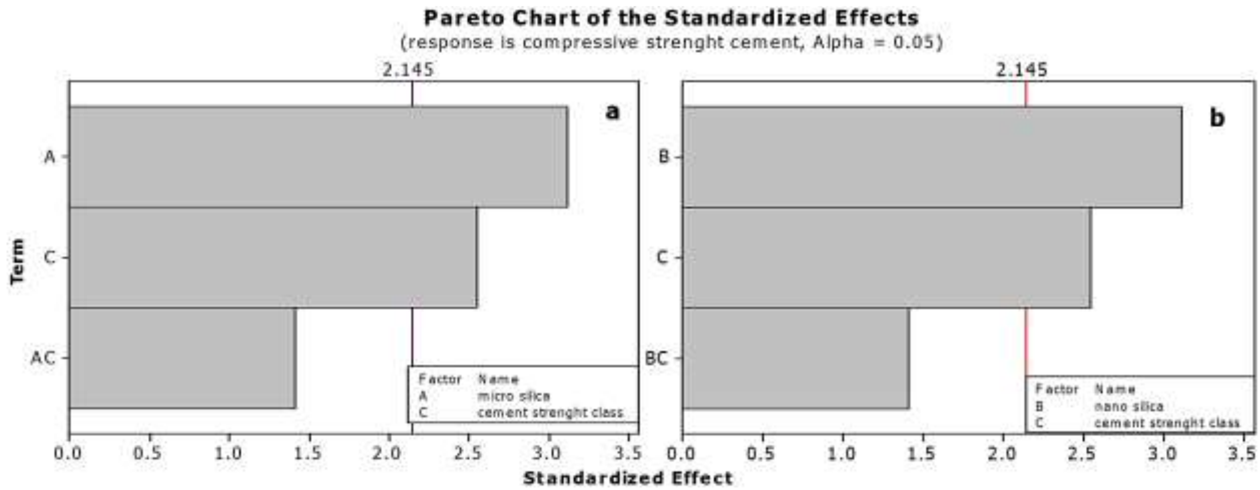

Figure 8. Pareto chart of the standardized effects

From the Pareto graph, they compare the relative size and statistical significance of the main and mutual effects. The Minitab software, when there is no error, shows the absolute value of unadjusted effects and, when there is an error, shows the absolute value of standardized effects. In general, the Pareto graph shows the absolute value of the effects and plotting the reference line in the graph in the value of t-value, which is equal to (1-a / 2). Every work that increases with the reference line is meaningful. In Figure 8a, the effect of A and C is significant and the greatest effect is A on the compressive strength, since it has the greatest expansion, but the AC model does not have a significant effect, and the interaction between A and C does not affect the compressive strength, and the interaction in the Pareto diagram means that the effect of a The agent depends on the amount and size of the other agent [52]. In Figure 8b, the effect of B and C is significant and has a significant effect on compressive strength and AC has no significant effect and does not have a significant effect on the output. This diagram shows that the compressive strength of concrete is more affected by micro- and nano-silica, while the interaction between micro- and nano-silica with less resistance to cement grade.

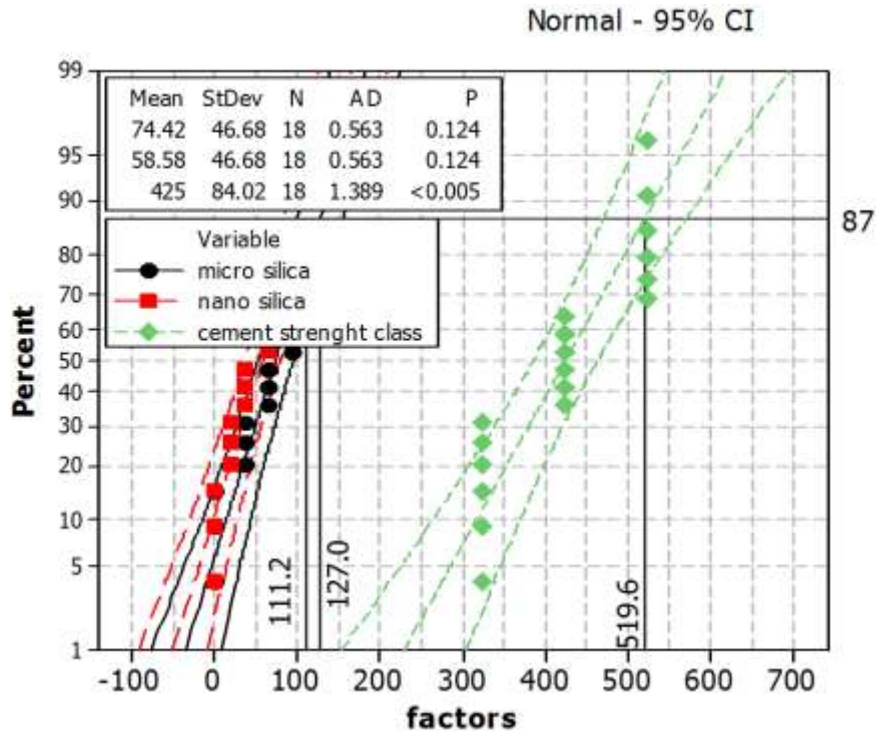

Figure 9. Probability plot of micro-silica , nano-silica, cement strength class

Use the probity plot graph to determine how your data is well-suited to specific distributions. They also use this graph to obtain evaluation parameters and cumulative percentages and compare sample distribution. The Minitab software draws data points to represent the actual cumulative distribution observed in the sample, with proportional cumulative distribution and confidence intervals based on the estimated parameters from the sample. This chart contains a Y axis for the conversion factor conversion scale and an X axis to represent the data values as well as points to show the actual cumulative distribution observed in the sample. Fit the line to compare how appropriate the distribution is to the real data. If the distribution is appropriate, you can use it to estimate the accumulation percentage.

The calculated points for micro- and nano-silica are relatively close to the distribution line, and p-value values for each Anderson Darling is greater than 0.05 and shows that the normal distribution is relatively good, but for the cement resistance category, given that the p-value is less than 0.05. So the normal distribution is not suitable for data. For micro- and nano-silica, because the distribution is appropriate with the data, we can use the fitting line for the evaluation of accumulation percentage. The estimated line is 87 per cent for micro-silica 127 and for nano-silica 111.2. The mean value for micro-silica is greater than the rest of the factors and is equal to 74.42. Also, the Anderson Darling is less than the resistance grade of cement for micro- and nano-silica. The best distribution for data is data that has the least amount of Anderson Darling. From Anderson Darling to compare the proper distribution of data to see which distribution is better or which specimens result from a particular distribution for testing. If samples have the smallest amount of Anderson Darling, that is, the closest fit to the data, but if, like here, the value of Anderson Darling for micro- and nano-silica is equal, the choice of the factor is based on practical and knowledge. In this diagram, micro-silica is more effective because the amount mean increases compressive strength.

5. Conclusion

In this study, the relationship between micro- and nano-silica with compressive strength of concrete has been investigated. One of the important activities in this study was the use of the DOE methodology, which uses the Taguchi and Factorial methods. By choosing three factors (micro- and nano-silica and resistance class of cement) as effective factors and assigning six different levels to each of them, the optimal combination of these factors as well as the effect of variables and even the severity of these effects was obtained. The results show that, at points, Optimum micro- and nano-silica have the highest compressive strength, and the optimum amount for nano-silica is 38 grams and for micro-silica is 95 grams. Also, experiments show that in compressive strength of cement 325, despite the presence of nano- and micro-silica, we have the highest compressive strength. As shown in the diagrams, when micro- and nano-silica are used concurrently, in the range where the nano-silica is in a low amount and the micro-axis is at its maximum, we have the highest compressive strength, and also when the nano-silica is maximal, the micro-silica should be at its lowest to maximize compressive strength.

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