Prediction the Strength of Fibered Reinforced Concrete Pavement Using Response Surface Methodology: Parametric Study

Mundher A. Abdulridha¹, Mohamed M. Salman², Qais Sahib Banyhussan¹*
¹Highway and Transportation Engineering Department, Mustansiriyah University, Iraq.
²Civil Engineering Department, Mustansiriyah University, Iraq.
*Corresponding author email: qaisalmusawi@uomustansiriyah.edu.iq

Abstract. Due to the pattern of load distribution in terms of load-carrying capacity, strength considered the major factor in design of pavement. For design the thickness of the rigid pavement, modulus of rupture (flexural strength) values used in the design procedure. The main purpose of the present study is to design optimum Eco-friendly concrete mixtures containing different amount of Fibers used in rigid pavement matching Iraqi requirements by using Response Surface Methodology (RSM). The experiments were designed using a thirty mixtures with four factors, namely, the cement content 300, 400 and 500 kg/m³, Steel fiber (0, 0.075, and 0.15 Vol.%), three different volume of Polypropylene fiber (0, 0.35 and 0.7 Vol.%), and 0, 5, and 10% Silica fume by weight of cement. The results stated that cement amount and steel fiber volume are the higher factors affecting the mechanical properties flowed by pp fiber and silica. Furthermore, a good correlation between the adopted variables and mechanical properties (compressive and flexural strength) was found through statistical models, where the correlation coefficients (R²) for all models were greater than 0.90. Optimal components to design concrete mixtures used in pavement that having compressive strength of (>30 Mpa) and flexural; strength of (> 4.1 Mpa) are cement 375 kg/m³, silica fume 0.002%, steel fiber 1.44e-005 (Vol.%), and PP fiber 4.53e-006(Vol.%).

Keywords: Fibred-reinforced concrete pavement; strength of concrete; RSM; Eco-friendly concrete

1. Introduction
Concrete is a certain man-made material used for pavement in the world. Regarding the structural capacity, it is the important part of concrete pavement because of its high elasticity modulus and rigidity. Due to the pattern of load distribution in terms of load-carrying capacity, strength considered the major factor in design of pavement. Modulus of rupture is the indicator of pavement strength by which the ability of pavement to resist failure in flexural can be measured. For design the thickness of the rigid pavement, modulus of rupture (flexural strength) values used in the design procedure.
Binder-rich (increased PC content) mixture compositions are required especially for high-performance concretes (HPC). In turn, it was found that manufacturing cement is used in concrete production causing 8 % to CO2 emissions [1]. Furthermore, cement amount may increase the risks of environmental unfriendliness and dimensional instability [2].

As mentioned above, despite attention about the manufacture of large quantities of (PC), the inclination of many current studies is to produce sustainable concrete mixtures [3-5]. The idea of producing more Eco-friendly concrete can be achieved by minimizing the amount of CO2 [6, 7]. Rich...
cement mixtures resulting in an increase in concrete strength. It may, in turn, cause shrinkage. Concrete may induce stresses that exceed its tensile capacity; cracks may therefore appear [8]. There is a common agreement that the compressive strength is 1/10 the maximum tensile strength. Britteness and dimensional instability are considered to be negative properties in concrete. Precautions must be taken to control cracking in a concrete pavement by removing or at least reducing cracks. The cracks decrease service life and increase maintenance costs [9]. The use of silica fume as part of concrete binders, particularly in the production of high-performance concrete and high strength. In addition, their use as mineral admixtures as partially contributes to sustainable concrete construction [10–12]. Incorporation silica fume into concrete led to modify the role of concrete aggregate [13]. It's reported that increasing silica fume increases the concrete strength regarding compressive and flexural strength [14, 15].

One possible way to reduce the concrete’s brittleness is to modify or develop concrete mixtures in which their behavior becomes more resistant to the cracking potential while remaining their high-performance characteristics. The inclusion of fibers into HPC produces a type of concrete known as High-Performance Fiber Reinforced Concrete (HPFRC). Reinforcing the concrete with small, randomly distributed fibers has increasingly been used in many applications, especially highway structures.

Furthermore, utilizing a single fiber system in concrete may improve such concrete properties. For example, micro-fibers have the ability to arrest micro-cracks thereby increasing its strength upon the first crack. On the other hand, the macro-fibers can restrain the macro-cracks and control the propagation of crack width; thus, an increase in post-strength and toughness are expected. There is complete agreement that, fiber synergy can be achieved by using two or more fibers which have a difference in type or length; this synergy leads to each fiber carrying out its function at a different stage from the other fibers.

The design of experiments (DoE) is one of ways to saving the time and costs by which can reduce the number of tests (trials). In the other word, the DoE seeks the choosing of most proper points (tests) in which the response (output) must be well examined. Thus, the use of experiment design has a great rule in selecting the connected response surface test [16]. Furthermore, the response surface methodology (RSM) has the ability to determine the impact between the independent factors, unlike other methods that takes the effect of each variable separately.

2. Purpose of the study
The main purpose of this study is to design optimum Eco-friendly hybrid fibred reinforced concrete mixtures containing silica fume used in rigid pavement in which matching Iraqi requirements by using Response Surface Methodology (RSM). In fact, producing the cement is accompanying with CO2 emissions. So, reducing the cement in concrete without sacrificing the concrete strength is one way to consider the concrete as environmentally friendly. The objective of this study is both to determine the effect of cement content, silica fume (MSF), steel fiber, and Polypropylene fibers on the Modulus of Rupture of the concrete pavement and finding the optimum conditions for the most cost-effective mix design.

3. Materials Used, Test, and Mixture Design
3.1 Material
3.1.1 Cement
The cement used throughout this work was Ordinary Portland Cement Type I (Tasluga Factory) with the commercial name. It was contained in airtight plastic containers to prevent exposure to various atmospheric conditions. The chemical analysis and the findings of the physical tests complied with the Iraqi standard No. 5/1984 [17]. The specific surface area (Blaine method), initial setting time, final setting time, soundness, compressive strength of the mortar at 3 days and compressive strength of the mortar at 7 days of the used cement were 394 m2/kg 115min, 4.87hour, 0.03%, 16.07 N/mm2 and
24.27 N/mm² respectively. The CaO, SiO₂, Al₂O₃, Fe₂O₃, MgO, SO₃, and L.O.I, of the used cement were 62.27%, 20.75%, 4.22%, 5.34%, 1.74%, 2.07%, and 1.86 respectively. All chemical tests were made by Baghdad University-Engineering college / Laboratories of Consulting Engineering Bureau.

3.1.2 Fine aggregate
The natural river sand from Al-Ukhaider region is used in concrete mix to achieve the mid-range gradient specification. It was separated into different sizes by sieve analysis equipment to choose optimum grading according to Iraqi specification (I.Q.S 45-1984) and it is chosen to match (SORB /R8,2003) [18]. The specific gravity, absorption, sulfate content and finesse modulus were 2.6, 0.85%, 0.254% and 2.5%, respectively. The particle size distribution is shown in Figure (1). All physical properties of fine aggregate were made at Material Laboratory in Engineering College of Mustansiriya University, except Sulfate content (SO₃), %, test was made by Baghdad University-Engineering college / Laboratories of Consulting Engineering Bureau.

![Figure 1. Gradation for Fine Aggregate.](image)

3.1.3 Coarse Aggregate
The crushed gravel from AL-Niba'ee region is used in concrete mix to achieve the mid-range gradient specification. The gravel was separated into different sizes by sieve analysis equipment to choose optimum grading according to Iraqi specification (I.Q.S 45-1984) and it's chosen to match (SORB /R8, 2003). Then, the aggregate was flushed and cleaned by water. The specific gravity, absorption, sulfate content and material passed from sieve No.200 (75 µm) were 2.63, 1.68%, 0.071%, and 0.0% respectively. The grading of coarse aggregate is shown in Figure (2).

3.1.4 Mixing Water
Water is an essential constituent of concrete mixture; it reacts chemically with Portland cement (hydration) to produce the desired concrete properties. Potable water was used in the casing and curing process.
3.1.5 Silica Fume
Micro Silica material has been used in concrete mixtures with different cement weight ratios. Micro-Silica Fume (MSF) is a pozzolanic material which is very active. It is a by-product of silicon or ferrosilicium metal products. For the silica fume used, the SiO2, SO3, and L.O.I were 94.5 percent, respectively 0.25 and 3.8. The results show that the MSF used satisfies ASTM C1240 specifications [19].

3.1.6 Fibers used in the study
Two different fibers were used herein, namely: hooked-end steel (S), and Polypropylene fibers. The properties of different fibers are shown individually in Table (1).

| Fiber type           | Length (mm) | Diameter (mm) | Tensile strength (MPa) | Elastic modulus (GPa) | Specific gravity |
|----------------------|-------------|---------------|------------------------|-----------------------|-----------------|
| Hooked-end steel (S) | 30          | 0.55          | 1185                   | 200                   | 7.80            |
| Polypropylene (PP)   | 12          | 0.05          | 689                    | 4                     | 0.9             |

3.2 Sample Preparing and Test
According to the main purpose of this investigation, prism specimens measuring 100×100×500 mm were cast, cured and then tested under four-point bending/loading to determine the flexural parameters: flexural strength based on Modulus of Rupture (MOR). Also, cubic specimens with a dimension of 100 mm were prepared for compressive strength evaluation. After 24 hours, both prismatic and cubic specimens were moved to be further cured in water until 7, 28 and 90 days were finished.

3.3 Mixtures design
Four factors are adopted in the present study namely; cement content, silica fume (MSF), steel fiber, and Polypropylene fibers to determine their effects on the modulus of rupture of the concrete pavement. It should be noted herein, the water to cementious ratio is fixed to 0.45 and course –to-fine aggregate ratio is 0.63. Factors and their levels are given in Table (2). Response Surface Methodology (RSM) is used for determining and optimizing the test results. Experimental factors and
their levels in the light of preliminary experience were sought. Response surface methodology (RSM) is a procedure that broadly adopted in optimizing the performance of system [20]. Thirty runs (mixtures) were used due to the four factors with three levels each (Table 3). The 30 mixtures were designed according to the Central Composite Design (CCD) which is the most famous of every single quadratic design and normally utilized in (RSM). The quantity of experimental samples can be given by the following equation:

\[
\text{Total No. of experiment} = (2^k + 2n + k) 
\]

(1)

In which \(k\) represents to the quantity of variables, \((n=6)\) is the quantity of center points [21].

**Table 2.** The four factors and the levels utilized in the study.

| Factors                  | low level | mean level | high level |
|--------------------------|-----------|------------|------------|
| Cement (kg/m\(^3\))     | 300       | 400        | 500        |
| Steel fiber (Vol.%       | 0.0       | 0.075      | 0.15       |
| Silica fume %            | 0         | 5          | 10         |
| Polypropylene fibers (Vol. %) | 0   | 0.35       | 0.7        |

**Table 3.** Array of experimental design by RSM.

| Run (Mixture No.) | Cement (Kg/m\(^3\)) | Steel Fiber (Vol. %) | PP (Vol. %) | SF % |
|-------------------|----------------------|----------------------|-------------|------|
| 1                 | 400                  | 0.075                | 0.35        | 5    |
| 2                 | 400                  | 0.075                | 0.35        | 5    |
| 3                 | 400                  | 0.000                | 0.00        | 10   |
| 4                 | 500                  | 0.000                | 0.00        | 10   |
| 5                 | 300                  | 0.000                | 0.00        | 0    |
| 6                 | 400                  | 0.075                | 0.70        | 5    |
| 7                 | 500                  | 0.150                | 0.70        | 0    |
| 8                 | 400                  | 0.075                | 0.35        | 5    |
| 9                 | 500                  | 0.075                | 0.35        | 5    |
| 10                | 500                  | 0.150                | 0.70        | 0    |
| 11                | 400                  | 0.075                | 0.35        | 5    |
| 12                | 400                  | 0.075                | 0.35        | 5    |
| 13                | 300                  | 0.000                | 0.00        | 10   |
| 14                | 500                  | 0.000                | 0.70        | 10   |
| 15                | 400                  | 0.150                | 0.35        | 5    |
| 16                | 500                  | 0.000                | 0.70        | 0    |
| 17                | 300                  | 0.000                | 0.70        | 10   |
| 18                | 300                  | 0.150                | 0.70        | 10   |
| 19                | 300                  | 0.150                | 0.70        | 0    |
| 20                | 500                  | 0.150                | 0.70        | 10   |
| 21                | 300                  | 0.000                | 0.70        | 0    |
| 22                | 300                  | 0.150                | 0.00        | 10   |
| 23                | 400                  | 0.075                | 0.00        | 5    |
| 24                | 300                  | 0.075                | 0.35        | 5    |
| 25                | 500                  | 0.150                | 0.00        | 10   |
| 26                | 300                  | 0.150                | 0.00        | 0    |
| 27                | 400                  | 0.075                | 0.35        | 5    |
| 28                | 400                  | 0.075                | 0.35        | 0    |
| 29                | 500                  | 0.000                | 0.00        | 0    |
| 30                | 400                  | 0.075                | 0.35        | 10   |
4. Experimental Results

As mentioned before, four variables: cement amount, Micro silica fume, steel fiber, and Polypropylene fiber were adopted to state their effects on the mechanical properties, compressive and flexural strength response. For Laboratory testing program, two response types have been explored in order to assess the mixtures proposed utilizing (CCD), to be specific: Compressive strength and flexural strength. In addition, the cost and the CO2 emissions for each mixture were estimated to take into account designing concrete mixture have low cost and low cement content (i.e low CO2 emissions). The CO2 emissions associated with the manufacturing of the binder materials used in this study were calculated based on values provided by the Environmental Protection Agency [22, 23]. The summary results of laboratory tests for mechanical properties, CO2 emissions and costs are shown in Table 4.

Table 4. Summary of results of mechanical properties

| Run (Mixture ID) | Kg CO2-e/m3 | Total Cost (US$/m3) | Compressive Strength (MPa) | Flexural Strength (MPa) |
|-----------------|-------------|---------------------|----------------------------|------------------------|
|                 |             |                     | 7-days 28-days 90-days 7-days 28-days 90-days |                        |
| 1               | 363.21      | 137.97              | 22.45 30.73 43.03 3.56 3.94 4.82           |
| 2               | 363.21      | 137.97              | 23.04 31.54 44.16 3.66 4.05 4.95           |
| 3               | 352.65      | 108.93              | 22.35 30.07 42.10 3.15 3.8 4.65            |
| 4               | 431.47      | 126.03              | 30.5 42.02 58.83 3.25 4.35 5.32            |
| 5               | 273.89      | 50.24               | 18.8 22.6 31.64 2.85 3.45 4.22             |
| 6               | 363.10      | 164.94              | 22.67 32.12 44.97 3.96 4.92 6.02            |
| 7               | 453.20      | 176.31              | 29.7 43.40 60.76 3.42 5.27 6.45            |
| 8               | 363.21      | 137.97              | 23.63 32.35 45.29 3.75 4.15 5.08            |
| 9               | 442.32      | 151.16              | 29.3 40.59 56.83 4.1 4.98 6.09              |
| 10              | 453.39      | 122.34              | 33.6 44.09 61.73 4.3 5.39 6.59              |
| 11              | 363.21      | 137.97              | 24.81 33.97 45.86 3.94 4.36 5.33            |
| 12              | 363.21      | 137.97              | 24.22 33.16 44.76 3.84 4.25 5.20            |
| 13              | 273.37      | 87.27               | 21.33 26.26 35.45 2.6 3.68 4.50             |
| 14              | 431.27      | 179.98              | 27.33 38.97 52.61 3.51 4.13 5.05            |
| 15              | 373.76      | 167.00              | 22.03 33.98 45.87 3.24 4.77 5.84            |
| 16              | 432.08      | 118.23              | 27.95 41.29 55.74 2.88 3.70 4.53            |
| 17              | 273.17      | 141.23              | 17.61 23.24 31.37 2.48 2.88 3.43            |
| 18              | 294.29      | 199.30              | 20.5 27.28 36.83 2.79 3.12 3.72             |
| 19              | 294.77      | 162.25              | 18.48 26.56 35.86 2.98 3.51 4.19            |
| 20              | 452.37      | 238.04              | 32.85 45.96 62.05 4.12 5.25 6.26            |
| 21              | 273.68      | 104.20              | 17.77 24.8 33.48 2.65 2.93 3.49             |
| 22              | 294.49      | 145.35              | 21.34 26.39 35.63 2.6 2.81 3.35             |
| 23              | 363.31      | 110.99              | 24.84 34.00 45.90 2.43 4.00 4.77            |
| 24              | 284.09      | 124.77              | 20.84 26.95 36.27 2.12 2.46 2.93            |
| 25              | 452.57      | 184.09              | 32.2 50.49 67.94 3.7 5.36 6.39             |
| 26              | 294.97      | 108.29              | 23.06 27.81 37.42 2.37 2.75 3.28            |
| 27              | 363.21      | 137.97              | 23.63 32.35 43.53 3.75 4.15 4.95            |
| 28              | 363.54      | 113.28              | 24.77 32.21 43.34 3.29 4.34 5.18            |
| 29              | 432.29      | 64.28               | 28.47 43.8 58.94 3.39 4.36 5.20            |
| 30              | 362.88      | 162.66              | 26.37 37.13 49.97 3.32 4.27 5.09            |

4.1 Screening and variables analyses

Screening analysis is a powerful tool used to investigate the influence of a set of variables on predicted compressive and flexural strength to choose the most essential contributing variables. The design of experiment (DOE) software was used in this paper which its outcomes are presented using a Pareto chart as shown in Figure 3. This figure shows the most essential parameters affecting compressive and flexural strength properties by order. Regarding compressive strength, which is shown in Figure 3 (a), the cement has the most significant impact on the values followed by steel fiber, pp fiber, and silica fume. The same behavior for flexural strength is observed as illustrated in Figure 3(b).
4.2 Effect of cement and Steel fiber on mechanical properties

After doing the screening, it is found those cement amount and steel volume are the higher factors affecting the mechanical properties. The experimental results are shown in Figure 4(a) indicated that compressive strength at higher amount of cement and steel showed more compliant. In addition, the flexural strength is affected by increasing both the cement and steel fiber (see Figure 4(b)).

5. Prediction of Mechanical properties behavior and ANOVA analysis

By using response surface methodology (RSM), the predicted models for compressive and flexural strength were found. This method is broadly adopted in optimizing the performance of system. In the present study, design of expert (DOE) software program was used for the statistical analysis and mathematical modelling. Analysis of variance ANOVA is valuable way of assessing the fitted model. ANOVA was conducted in order to achieve the interaction between the different parameters and the impact of each individual parameter. For a respectable model fit, the coefficient of determination ought to be a minimum of 0.80. A high R2 value near to 1.00 demonstrates a desired and reasonable agreement between the observed and calculated results.

As shown in Table 5, for compressive strength model, p-values which are less than 0.0001 indicate that the model is significant for 95% confidence intervals. The R values specify that there is a good
correlation between actual and predicted values. The Model F-value of 215.53 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Furthermore, the "Pred R-Squared" of 0.9279 is in reasonable agreement with the "Adj R-Squared" of 0.9367; i.e. the difference is less than 0.2.

Regarding flexural strength response, Table 6 shows the analysis of variance where the p-value for the model is less than 0.0001 with F-value of 37.29. Moreover, the "Pred R-Squared" of 0.8488 is in reasonable agreement with the "Adj R-Squared" of 0.8825; i.e. the difference is less than 0.2.

Table 5. Analysis of ANOVA for compressive strength responses.

| Source     | F Value | p-value Prob > F | R²  | Adj.R²  | Pred- R²  | Remarks    |
|------------|---------|-----------------|-----|---------|-----------|------------|
| Model      | 215.53  | < 0.0001        | 0.941 | 0.936  | 0.9279    | significant|
| A-cement   | 416.12  | < 0.0001        |       |         |           |            |
| B-steel Fiber | 14.95  | 0.0006          |       |         |           |            |

Table 6. Analysis of ANOVA for flexural strength responses.

| Source     | F Value | p-value Prob > F | R²  | Adj.R²  | Pred- R²  | Remarks    |
|------------|---------|-----------------|-----|---------|-----------|------------|
| Model      | 37.29   | < 0.0001        | 0.906 | 0.882  | 0.848     | significant|
| A-cement   | 164.14  | < 0.0001        |       |         |           |            |
| B-steel Fiber | 17.41  | 0.0004          |       |         |           |            |
| C-pp       | 0.14    | 0.7141          |       |         |           |            |
| AB         | 24.00   | < 0.0001        |       |         |           |            |
| BC         | 7.39    | 0.0123          |       |         |           |            |
| A²         | 10.64   | 0.0034          |       |         |           |            |

The final regression models, in terms of the independent variables and responses, are expressed by the equations (2), and (3) for compressive and flexural strength, respectively.

**Compressive Strength (Mpa) = -2.37600 + 0.086239 * A + 21.79259 * B ........ (2)**

Where; A= Cement (Kg/m³), B=steel fiber (Vol. %)

**Flexural Strength = -3.25833 + 0.032219 * A - 17.13333 B + 0.045667 * A * B + 7.23810 * A * C - 3.40000E-005 * A² ........(3)**

Where; A= Cement (Kg/m3), B=steel fiber (Vol. %), pp= Polypropylene fiber (Vol.%)

6. Optimization of Preparation Parameters

An optimization process was implemented to determine the optimum value of cement, silica fume, Steel fiber and PP fiber. Based on the software optimization step, the preferred goal for each mix design parameter was selected within the ranges required value. For compressive and flexural strength were set to greater than (30 Mpa) and 4.1 (Mpa) which they are minimum requirements for design concrete pavement (SORB, 2003)[18]. Minimizing CO2 and cost were set to design Eco-friendly mixtures. It should be noted herein that the cost of each mixture was estimated by taking into account the cost of all the ingredients, for example, the cost of cement, sand, gravel, water etc. in one cubic meter of mixture. Same estimation was made regarding CO2 emission, where the emissions were
adopted according to the previous studies that found estimated emissions to produce a certain material, for example, the CO2 emission resulted from manufacturing the steel fibers, cement etc.

According to the adopted procedure, the finalized cement, silica, F/A, and W/C are found. The results of the optimum value of variables and their response are listed in Table (7).

Table 7. The optimum variables with their responses

| Responses          | Unit       | Optimal results | Desirability |
|--------------------|------------|-----------------|--------------|
| Cement             | Kg/M³      | 375             | 0.9          |
| Silica fume        | %          | 0.002           |              |
| Steel Fiber        | Vol.%      | 1.44e-005       |              |
| PP fiber           | Vol.%      | 4.53e-006       |              |
| Compressive Strength| Mpa       | 30              |              |
| Flexural Strength  | Mpa        | 4.07            |              |
| CO₂ emission       | Kg CO₂ e/m³| 333.4           |              |
| Total Cost         | US$        | 55.5            |              |

7. Conclusions
In the present study, efforts were made to design Eco-friendly concrete mixtures taking into account lowering the costs and CO2 emissions through using low cement, where matching the Iraqi requirements regarding compressive and flexural strength. The following conclusions were drawn:

- It is found that cement amount and steel fiber volume are the higher factors affecting the mechanical properties followed by pp fiber and silica.
- Furthermore, a good correlation between the adopted variables and mechanical properties (compressive and flexural strength) was found through statistical models, where the correlation coefficients R² for all models were greater than 0.90.
- Optimal components to design concrete mixtures used in pavement that having compressive strength of (>30 Mpa) and flexural strength of (> 4.1 Mpa) are cement 375 kg/m3, silica fume 0.002%, steel fiber 1.44e-005 (Vol.%), and PP fiber 4.53e-006 (Vol.%).

References
[1] Andrew R M 2018 Global CO2 emissions from cement production *Earth Syst. Sci.*, 10, 2213–2239.
[2] Yıldırım G 2019 Dimensional stability of deflection-hardening hybrid fiber reinforced concretes with coarse aggregate: suppressing restrained shrinkage cracking *Struct. Concr.*, 20, 836–850.
[3] Flatt R J, Roussel N and Cheeseman C R 2012 Concrete: an eco material that needs to be improved *J. Eur. Ceram. Soc.*, 32, 2787–2798.
[4] Proske T, Hainer S, Rezvani M. and Graubner C A 2014 Eco-friendly concretes with reduced water and cement content–Mix design principles and application in practice *Constr. Build. Mater.*, 67, 413–421.
[5] Damineli B L, Kemeid F M, Aguiar P S and John V M 2010 Measuring the eco-efficiency of cement use *Cement Concr. Compos.* 32, 555–562.
[6] Worrell E, Price L, Martin N, Hendriks C and Meida L O *Annua*. 2001 Carbon dioxide emissions from the global cement industry *Rev. Energy Environ.*, 26, 303–329.
[7] Hendriks C A, Worrell E, De Jager D, Blok K and Riemer P1998 Carbon dioxide emissions from the global cement industry Proc. 4th Int. Conf. On Greenhouse Gas Control Technologies, 939–944.
[8] Whiting D A, Detwiler R J and Lagergren E S 2000 Cracking tendency and drying shrinkage of silica fume concrete for bridge deck applications *ACI Materials Journal*, 97(1).
[9] Boulfiza M, Sakai K, Banthia N and Yoshida H 2003 Prediction of chloride ions ingress in uncracked and cracked concrete *ACI Materials Journal*, 100(1), 38–48.
[10] Aitcin P C 1998 High-performance concrete E & FN Spon, London, 591.
[11] Malhotra V M and Mehta P K 1996 Pozzolanic and cementitious materials Advances in concrete technology, Vol. 1.
[12] Monteiro P 2006 Concrete – microstructure properties and materials, 3rd ed McGraw-Hill Publishing.
[13] Bentur A, Goldman A and Cohen M D 1987 Contribution of transition zone to the strength of high-quality silica fume concretes MRS Online Proceedings Library Archive, 114.
[14] Mazloom M, Ramezaniapour A A and Brooks J J 2004 Effect of silica fume on mechanical properties of high-strength concrete Cement & Concrete Composites, 26(4):347–57.
[15] Bhanja Sand Sengupta B 2005 Influence of silica fume on the tensile strength of concrete Cement and Concrete Research, 35(4):743–7.
[16] Banyhussan Q S, Hanoon A N, Al-Dahawi A, Yıldırım G and Abdulhameed A. A. 2020 Development of gravitational search algorithm model for predicting packing density of cementitious pastes Journal of Building Engineering, 27, 100946.
[17] Iraqi specification No.451984, “Portland Cement”,
[18] SCRB 2003 General Specifications for Roads and Bridges Ministry of Housing and construction, Iraq, section R8, State Corporation of Roads and Bridges
[19] ASTM C1240 2006 Standard Specifications for Silica Fume Used in Cementitious Mixtures Annual Book of the American Society for Testing and Materials, Standards 04 200-208
[20] Bezerra M A, Santelli R E, Oliveira E P, Villar L S, Escaleira LA 2008 Response surface methodology (RSM) as a tool for optimization in analytical chemistry Talanta 76.
[21] Khuri A I and Cornell J A 1996 Response surfaces: designs and analyses 2nd ed. New York,USA: Marcel Dekker, Inc.
[22] U.S. Environmental Protection Agency 2009 Technical Support Document for Process Emissions from Cement Office of Air and Radiation, Washington, DC, pp 26.
[23] EPA 430-R-11-005, 2011 Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2009 U.S. Environmental Protection Agency, Washington, DC, pp 459.

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