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EFFECT POLYPROPYLENE OF FIBER ON DRYING SHRINKAGE CRACKING OF CONCRETE PAVEMENT USING RESPONSE SURFACE METHODOLOGY

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Abstract: In concrete when tensile stress surpasses the strength of the traction contributes to cracking, which is called shrinkage cracking. Shrinking allows for curling and folding of concrete. The principal goal of this research work is to develop optimal Eco-friendly concrete mixtures by using Response Surface Methodology (RSM), including different quantities of polypropylene fiber used in concrete pavement, identify the shrinkage factor (shrinkage cracking) in the concrete pavement. The testing program included using of thirty mixtures to investigate four parameters namely cement content (300,400 and 500) kg / m3, steel fiber (0, 0.075, and 0.15 vol. %), three separate amounts of polypropylene fiber (0, 0.35, and 0.7 vol. %), and (0, 5, and 10 %) silica fume by cement weight. The results indicated that the amount of cement is the higher factors affecting the shrinkage cracking of concrete. For the purpose of obtaining the best mixture for optimal components to design concrete mixtures used in the concrete pavement that give the compressive strength [> 30 MPa], flexural strength [> 4.1 MPa], minimum CO2 emissions, less cost, and fewer cracks width according to requirements and Iraqi specifications are cement [385.94] kg/m3, silica fume [0.000198Vol.%], steel fiber [0.0564 Vol.%], PP fibers [0.2926 Vol.%], Carbon dioxide emissions [379.59] kg CO2 -e / m3, total cost 99.96 USD / m3, and crack width [0.1]mm.

Keywords: *concrete pavement Eco-friendly concrete; Polypropylene; RSM; Shrinkage cracking; Silica fume.*

1. Introduction

Concrete is a certain manufactured material. Regarding the structural capacity, it is an important part of concrete pavement because it has high modulus of elasticity and rigidity. Furthermore, the cement amount may increase the risks of environmental unfriendliness and dimensional instability. A constrained ring test is provided a detailed assessment of concrete material's cracking capacity [1]. The cracking of concrete pavement is a big concern in terms of the costs of building and maintenance of pavements. These cracks dramatically shorten concrete service life by speeding up freeze-thaw damage and exposing the steel reinforcement to corrosive salts. These cracks provide routes for water, oxygen, and deicing salts and carbon to penetrate through the concrete reinforcement steel; these routes can pass partially or fully through the concrete slab. General the tensile strength corresponds to less than of its compressive strength. As tensile stresses in concrete exceed the concrete's tensile strength, cracks start to appear [2].

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Many variables may contribute to the formation of concrete pavement tensile stresses, such as plastic concrete settlement over reinforcement, plastic shrinkage, drying shrinkage, thermal shrinkage, and traffic loading. Such variables are determined primarily by real property, environmental conditions, and concrete structural [3]. Steel fibers have stronger flexural strength performance, but relatively poor action in reducing speed and cracking the minimal shrinkage time. Except for the polypropylene-containing mixture [4]. There was no previous local research study for restrained shrinkage. So in the study researched the effects of available local market materials on shrinkage cracks.

This study's overall objective is to investigate the shrinkage cracking behavior of concrete pavement and design optimum Eco-friendly hybrid fibred reinforced concrete mixtures containing, polypropylene, steel fiber, and silica fume used in the rigid pavement in which matching Iraqi requirements [5] by using Response Surface Methodology (RSM).

2. Methodology

2.1. Material

2.1.1 .Cement

The cement used in this work was Ordinary Type I Portland Cement with the trade name (Tasluga Factory). It was stored in airtight plastic containers to avoid exposure to varying ambient conditions. The chemical analysis and the findings of the physical tests complied with the Iraqi standard [6]. Wherever the Tables (1) and (2) show the chemical and physical properties of the cement used in this research. Baghdad University-Engineering college / Consultant Research Bureau Laboratories performed all chemical.

Table 1. Chemical Composition of Cement

property	**Test results**	**Specification Limits**
CaO (%)	62.27	Not limited
SiO_2 (%)	20.75	Not limited
Al_2O_3 (%)	4.22	Not limited
Fe_2O_3 (%)	5.34	Not limited
MgO (%)	1.74	Max.5
SO_3 (%) $C_3A<5\%$	2.07	2.5
Max. $C_3A>5\%$	Not applicable	2.8
Loss on Ignition (%)	1.86	Max.4
Insoluble residue (%)	0.61	Max.1.5
Lime saturated Factor (%)	0.91	0.66 - 1.02
Compound composition	Test results	Specification Limits
C_3S (%)	53.82	Not limited
C_2S (%)	18.56	Not limited
C_3A (%)	2.16	Not limited
C_4AF (%)	16.23	Not limited

Table 2. Physical Properties of Cement

property	**Test result**	**Specification Limits**
Setting time		
Initial setting (mins)	115	Min. 45
Final setting (hrs.)	4.87	Max. 10
Compressive strength (Map) at age:		
3 days	16.07	Min. 15
7 days	24.27	Min. 23

2.1.2. Fine aggregate

The normal river sand from the Al-Ukhaider area was used in a concrete mix to achieve the requirements for the mid-range gradient. It was divided into various sizes by sieve analytical equipment to pick the optimal grade according to the Iraqi standard [5] and is selected to Iraqi specification, R10. The specific gravity, absorption, sulfate content, and finesse element are shown in the Table (3). The distribution of particle size can be seen in Figure (1). All physical properties of fine aggregate which was conducted at Laboratory of Engineering Collage / University of Baghdad

Table 3. Physical properties and sulfate content of fine aggregate

Properties	Results Test	Limits of Specification
Finer than 0.075 mm	2.5	Max. 5
Specific gravity	2.6	Not limited
Absorption, %	0.85	Not limited
Sulfate content (SO_3), %	0.254	Max.0.75

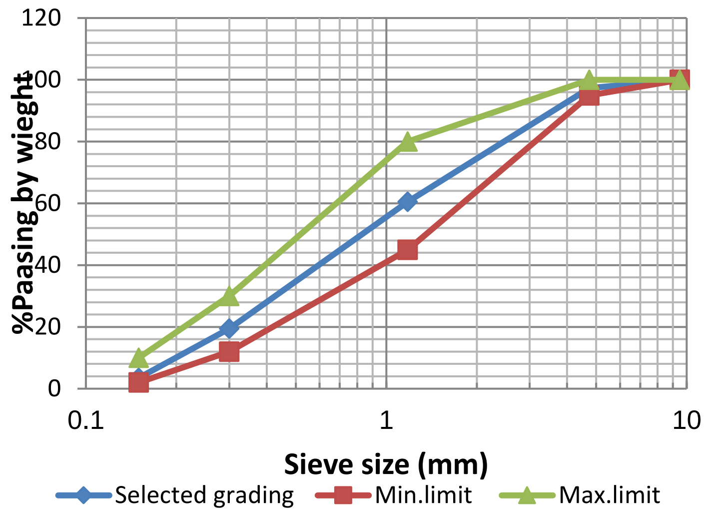

Figure 1. Gradation for Fine aggregate according to (SCRB-R10- 2003) [5]

2.1.3. Coarse Aggregate

To meet the mid-range gradient requirements, the crushed gravel from the AL-Niba'ee area was used in the concrete mix. The gravel was sorted by sieve analysis equipment into various sizes to select the optimal grade according to the Iraqi standard [5]. The mixture was then drained and water-cleaned. The specific gravity, absorption, sulfate content, and substance removed from Sieve No.200 (75 μm) are shown in the Table (4).The coarse aggregate grade is shown in Figure (2).

Table 4. Physical properties and sulfate content of Coarse aggregate

Properties	Results Test	Limits of Specification
Finer than 0.075 mm	0.0	Max. 3
Specific gravity	2.63	Not limited
Absorption, %	1.68	Not limited
Sulfate content (SO_3), %	0.071	Max.0.1

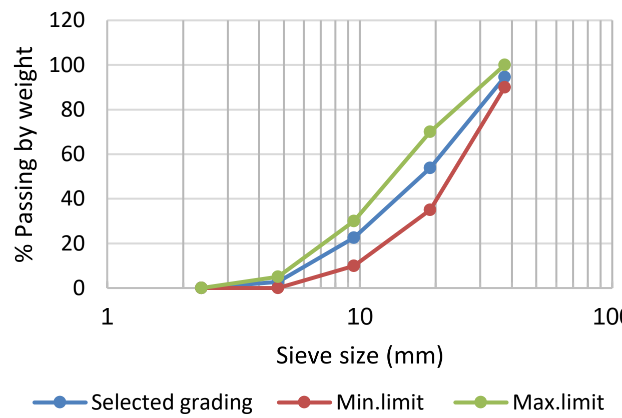

Figure 2. Gradation for Coarse aggregate according to (SCRB-R10- 2003) [5]

2.1.4. Mixing Water

Water is an essential element of the concrete mixture; to achieve the desired concrete properties, it reacts chemically with Portland cement (hydration). Pure water was used during the mixing and curing process.

2.1.5. Fiber use in the study

Two different types of fibers were used: steel with gooseneck (S) and polypropylene (P.P) fibers.

Steel fibers with curved ends with length 30 mm and 0.55 mm diameter were used in this study. The standard amount of steel fibers expressed as % Vf (Volume Fraction of Steel Fiber) percent. The physical properties are tensile strength 1185 MPa, elastic modulus 200 GPa, and specific gravity 7.8.

PP Fiber article was used in concrete mixes with different weight ratios of cement. The polypropylene raw material is a solely hydrocarbon monomeric (C_3H_6) deal. The specific gravity is (0.9), the outside color of the fibers is white, the melting point is (160℃), the fiber diameter is (30-50) microns, and the Tensile strength is (137-689) MPa. Elastic modulus is (3.4-4.8) GPa, the elongation is (25-40%) and the cutting length of the fiber is (12) mm. The properties of different fibers are shown individually in Table (5) and (6).

Table 5. Physical properties of steel fiber

No.	Inspection items	Requirement	Test result
1	Tensile Strength (Mpa)	≥1100	1185
2	Length (mm)	30 ± 5%	30.1
3	Diameter (mm)	0.55 ± 5%	0.56
4	Ratio	55 ± 5%	54
5	Flexural properties	Cold 90º	10/10 un-break
6	Qualified rate of shape%	≥90	99
7	Impurity content %	≤1	0.1

Table 6. Physical and Chemical properties of PP Fiber

Composition:	100% virgin Polypropylene
Appearance:	Fibrillated mini bundle
Specific gravity:	0.9
Tensile Strength:	137 - 689 MPa.
Modulus Young's:	3.4 - 4.8 GPa.
Toughness:	8.82 GPa.
Elongation:	25 – 40 %
Softening point:	150 C.
Melting point:	160 C.
ignition point:	580 C.
Length fiber:	12mm
Chloride content:	Nil
Sulphate content:	Nil
Alkali content:	Nil

2.2. Sample Preparing and Test

2.2.1. Sample Preparing

According to the major goal of this study, prism specimens measured (100×100×500) mm were cast and then tested for flexural parameters under four-point bending-loading: flexural strength dependent on Modulus of Rupture (MOR), cubic specimens with a dimension of (100*100*100) mm were also prepared for the measurement of the compressive strength. Both prismatic and cubic specimens were transferred after 24 hours to be cured in water before test at (7 , 28, and 90) days as shown in Plate (1), and rings specimens were cast and prepared for crack width testing an according to the dimensions shown in Figure (3) and Plate(1). After 24 hours, the specimens were moved to be further cured in the control room until (30) days were finished.

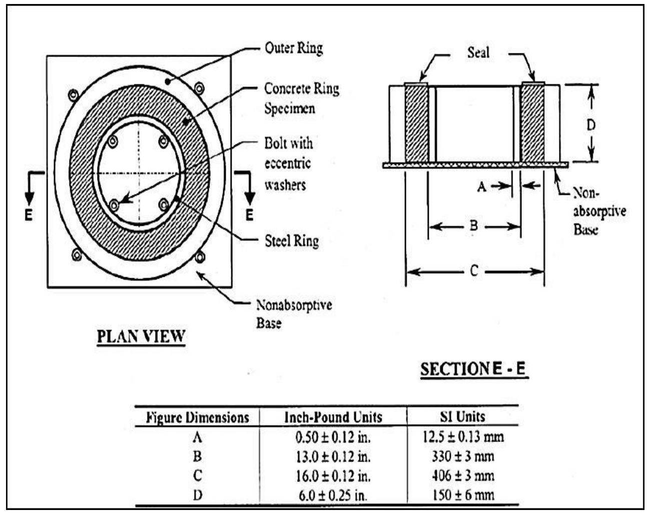

Figure 3. Test Ring ASTM

Plate 1. Molds Used for Specimen Preparation

2.2.*2 Sample Test*

2.2.2.1. Compressive Strength Test

Concrete pressure force is verification of hardy concrete mixtures. This review is more relevant, and gives an idea of all the features of concrete [7]. Where a concrete compression test was completed according to the standard specifications. Where sample formed cubes [100 * 100 * 100] mm were used. Wherever nine samples were prepared for each experimental combination and at the rate of three samples for each analytical life (7, 28, and 90) days, where compression strength was determined an average of three sample results.

2.2.2.2. Flexural Strength [modulus of rupture] Test

The Flexural Strength is one of the most critical aspects to conclude the rigid pavement concert. The test was carried out on prism samples with measurements of (100 * 100 * 500) mm and in compliance with standard requirements [8] [ASTM-C 78-18] where the loading in four points and at the age (7, 28, and 90) days with three samples per age.

2.2.2.3. Restrained shrinkage Test

In this research, shrinkage cracking was tested. The samples were of one ring per mixture, and the out ring of the mold were opened after a period of (24) hours after the concrete mixture has been inserted into the formwork and the work is completed. Samples are transferred to a designed control room in terms of the required temperature and humidity by using electric heaters, fans, and basins filled with water inside the room for the purpose of distributing heat and humidity, and heaters and fans are connected to the electric board outside the control room. Microscope linked to a computer where samples are examined from the age of one day to the age of 28 days. The required temperature is (23 ± 2) degrees Celsius and the required relative humidity (RH) for testing is (50 ± 4%) [9]. At the end of the test, the number of cracks is determined for the experimental concrete mixes, where three readings are made in three different places to determine the width of the cracks. Design control room is shown in the Plate (2). Plate (3) shows cracks reading. The age of the crack was identify by used a Microscope linked to a computer where samples are examined from the age of one day to the age of 28 days.

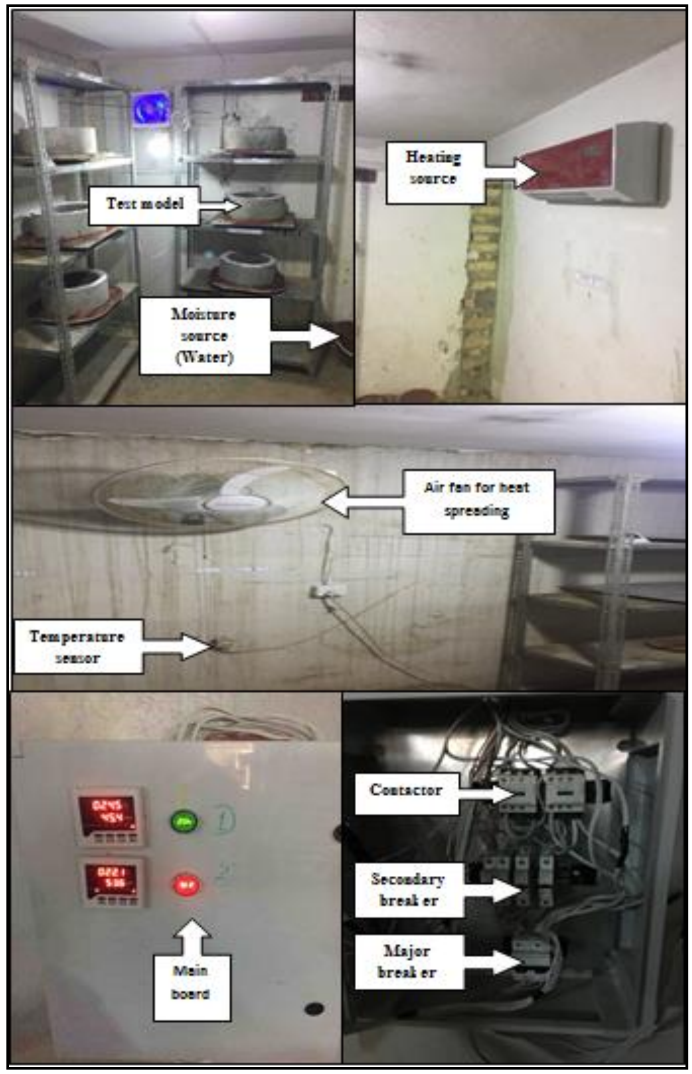

Plate 2. Control room temperature and treatment tools and samples

Plate 3. Reading Crack width for Ring

2.3. Mixtures Design

The aim of this study is to identify the substantial shrinkage factor (shrinkage cracking) in the concrete pavement, evaluate the influence of various constituent components, such as the contents of cemented concrete and mixtures, on this shrinkage cracking. According to the maximum aggregate size and strength requirement [5], the water-to- cement ratio is set at 0.45 and the ratio of course-to-fine aggregate is 0.63. Table (7) offers the variables and their ratios used in the study. The Response Surface Methodology (RSM) is used to assess and refine the test outcomes. Experimental parameters and their thresholds were obtained in light of limited knowledge. The Response Surface Methodology (RSM) is one of the helpful statistical techniques commonly used in maximizing the efficiency of any process or system. [10]. According to the four variables of three levels each, thirty runs (measures) were used as shown in Table (8). The 30 mixtures were designed in conjunction with the Central Composite Design (CCD), the most popular of all quadratic designs, and usually used in (RSM).

Table 7. The four factors and the levels utilized in the study

Factors	Levels		
	low level	mean level	high level
Cement (kg/m3)	300	400	500
Steel fiber (Vol. %)	0.0	0.075	0.15
Silica fume%	0.0	5	10
Polypropylene fibers (Vol. %)	0.0	0.35	0.7

Table 8. Array of experimental design by RSM

Run (Mixture No.)	Cement	Steel Fiber (Vol. %)	PP (Vol. %)	SF %
1	400	0.075	0.35	5
2	400	0.075	0.35	5
3	400	0.000	0.35	5
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	0.00	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

3. Results

3.1. Experimental Results of mechanical properties of concrete

As previously stated, four variables were tested: cement quantity, silica fume, steel fiber, and P.P fiber to indicate their effects on mechanical properties; compressive strength, and flexural strength. Table (9) provides the description of experimental test findings for mechanical properties.

3.1.1. Screening and variables analyses

Screening analysis is an effective method used to analyze the effect of a series of variables on the expected compressive strength, flexural strength, and elasticity feature in choosing the most significant contributing variables. The design of the experiment (DOE) was used in this section which presents its findings using a Pareto chart by using Minitab software, as shown in Figure

(4). This figure displays by order the most important parameters concerning compressive and flexural strength properties. With respect to compressive strength as shown in Figure (4(a)), cement has the largest effect on the values accompanied by P.P fiber, steel fiber, and silica fumes. As seen in Figure (4(b)), the flexural strength effect by cement on values followed by steel fiber, P.P fiber, and silica. The result shows that compressive strength at a high amount of cement and steel fiber presented more accepting and give less compressive strength with the increase of P.P fiber with the increase of cement amount. And flexural strength at a high an amount of cement and steel fiber was more than with an increase of P.P fiber with an increase of cement amount.

Table 9. Summary of results of mechanical properties of concrete

Run	Compressive Strength (MPa)			Flexural Strength (MPa)		
	7-days	28-days	90-days	7-days	28-days	90-days
1	21.78	29.81	41.74	3.56	3.94	4.82
2	22.35	30.59	42.87	3.66	4.05	4.95
3	21.70	29.20	44.14	3.15	3.80	4.50
4	29.60	42.80	54.02	3.25	4.35	5.32
5	18.30	22.60	40.88	2.85	3.45	4.35
6	22.80	31.20	42.63	3.96	4.92	5.86
7	28.80	42.49	54.98	3.40	5.27	5.55
8	22.92	32.70	42.94	3.75	4.15	5.08
9	28.42	41.40	52.60	4.00	4.98	6.70
10	33.60	42.77	61.09	4.10	5.39	7.2
11	24.07	31.96	44.80	3.94	4.36	5.13
12	23.50	32.21	43.47	3.84	4.25	5.20
13	20.70	25.52	37.60	2.40	3.68	4.77
14	26.50	37.83	51.03	3.51	4.13	4.50
15	21.40	32.85	48.21	3.24	4.77	5.03
16	33.03	42.22	57.42	2.88	3.70	4.73
17	15.40	20.54	30.43	2.48	2.88	3.77
18	18.50	22.70	35.73	2.80	3.12	3.89
19	17.93	20.81	33.78	2.68	3.51	3.80
20	31.90	44.60	58.43	3.65	5.25	6.17
21	17.24	23.06	31.42	2.66	2.93	3.27
22	20.70	24.41	34.40	2.50	2.81	3.50
23	24.09	33.90	44.52	2.43	4.00	4.77
24	20.21	26.20	35.20	2.12	2.46	3.15
25	31.23	46.58	63.34	3.21	5.36	6.39
26	22.06	26.98	36.30	2.37	2.75	4.28
27	22.92	31.43	42.22	3.65	4.15	4.95
28	22.30	27.12	38.05	3.29	4.34	5.33
29	30.2	41.50	62.18	3.40	4.36	5.75
30	25.58	36.02	46.07	3.82	4.27	5.18

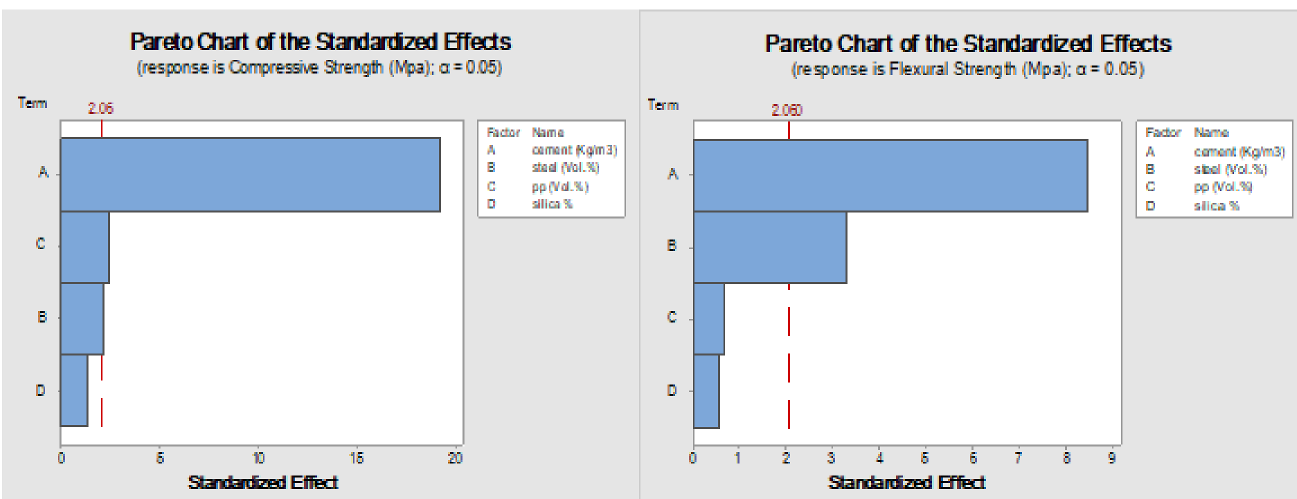

Figure 4. The outcomes of the screening analysis for (a) The Compressive Strength, (b) Flexural Strength

3.1.2. Effect of polypropylene on mechanical properties

Polypropylene fiber caused an increase in compressive strength then improved the amount of polypropylene fiber induces an increase in compressive strength, the use of polypropylene fiber in 0.35 % induces an increase in compressive strength of almost 16.6 %, an increase of polypropylene fiber to 0.7 % leads to an increase of compressive strength of almost 1.99 % relative to a combination of 0 %. Using polypropylene fiber at 0.35 % increases flexural strength by almost 43.5 %; increases polypropylene fiber to 0.7 % because the flexural strength improves by almost 17.8 % relative to the 0 % polypropylene fiber combination.

3.2. Experimental Results of shrinkage cracking

A constrained ring test may provide a detailed assessment of concrete materials' cracking capacity [11]. The cracking capacity of concrete was graded based either on the stress intensity at the time of cracking or on the time of cracking individually. The cracking capacity was estimated in the present study based on time to crack. Cracking time is the difference between cracking age and the period at which shrinkage is begin [11, 12] . The four variables: cement amount, silica fume, volume steel fiber content, and volume P.P fiber content were expected to demonstrate their influence on the width and length of the cracks, in experimental mixtures of test specimens using the ring, Where the width of the cracks in the Rings are determined using the Microscope tester. Result of ring cracks are shown in Table (10) that shows the time to cracking, number, width, length, and area of cracks. Figure (5) shows the relationship time to cracks and mixers for the ring.

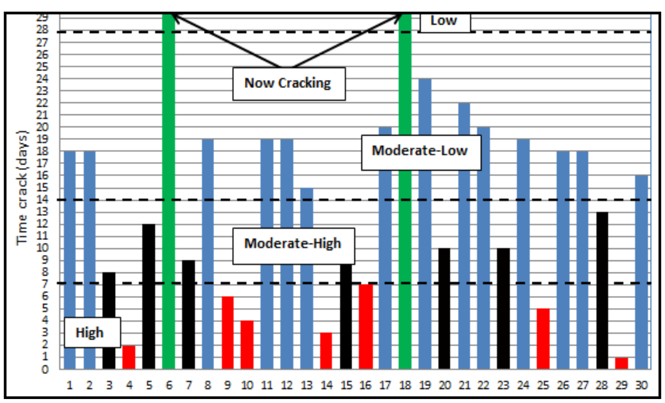

Figure 5. Relationship Time Cracks and mixers for Ring

Table 10. Summary of results Ring crack at age 28 days

Run mix.	Time to Cracking (days)	No. of Crack	Length of cracks (mm)	Width crack (mm)	Area of cracks (mm2)
1	18	3	150	0.051	7.65
2	18	3	150	0.052	7.80
3	8	2	150	0.182	27.75
4	2	1	150	0.756	113.40
5	12	2	120	0.030	6.48
6	28	0	0	0	0
7	9	3	150	0.129	19.35
8	19	3	140	0.047	6.58
9	6	3	150	0.506	75.90
10	4	3	150	0.623	93.45
11	19	3	130	0.047	6.11
12	19	3	140	0.049	6.72
13	15	2	150	0.348	52.20
14	3	3	150	0.156	22.50
15	9	3	140	0.106	14.84
16	7	2	140	0.185	25.90
17	20	3	120	0.064	7.68
18	28	0	0	0	0
19	24	3	130	0.023	2.99
20	10	2	140	0.102	14.28
21	22	2	120	0.079	9.48
22	20	1	150	0.252	37.80
23	10	1	150	0.354	53.10
24	19	3	140	0.219	30.66
25	5	1	150	0.512	76.80
26	18	2	120	0.256	30.72
27	18	2	140	0.051	7.14
28	13	3	150	0.073	10.95
29	1	1	150	0.974	146.10
30	16	3	140	0.010	1.40

3.2.1. Screening and variables analyses

The method of inspection analysis was used in this research because it is a powerful tool for investigating the effect of additives on the concrete shrinkage cracks, which in effect changes the width and duration of the cracks and thus we find more important variables and add to the shrinkage cracking in the concrete mixture where the designer of the experiment (DOE) was used and have shown results using Pareto chart as seen in the Figures (6). Where it has been found from the illustration that an added P.P fiber is more significant and contributes to the process of reducing shrinkage cracking, because the greater the amount of addition, the less crack width, and hence the cracks are reduced. And then were noted the result that the cement used causes, that is, the larger the cement volume, the greater the width cracks, and the time to crack increase followed by steel fiber and the silica fume content. The result shows that crack width at a less amount of cement and P.P fiber presented more accepting and give less crack width with the increase of steel fiber with the increase of cement amount.

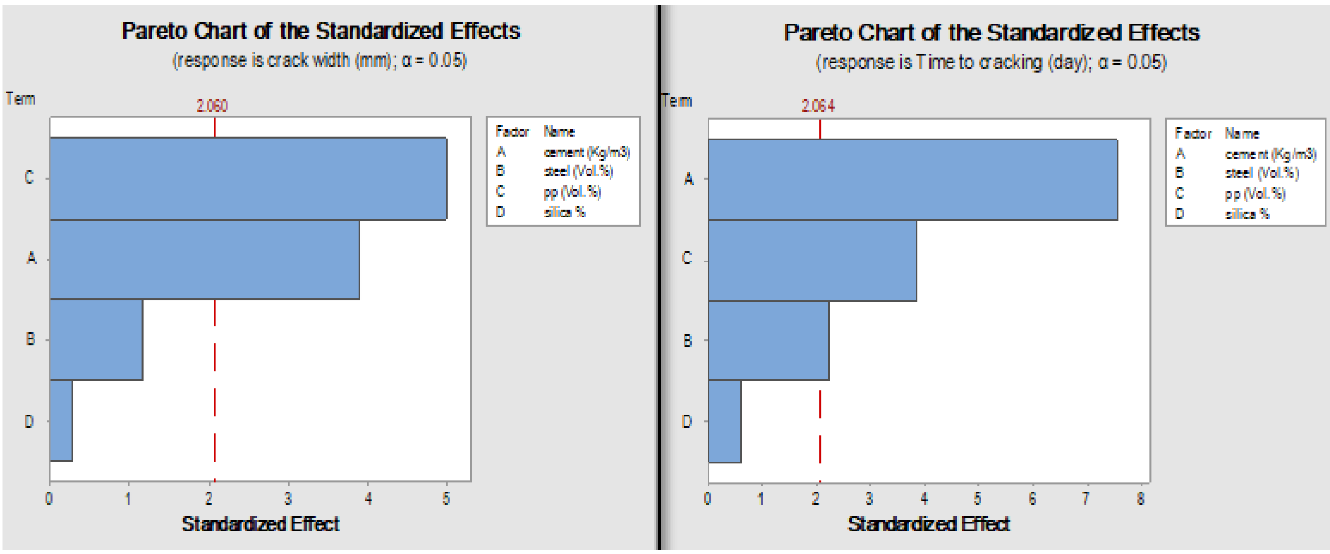

Figure 6. The outcomes of the screening analysis for (a) The Crack Width, (b) Time to Cracking

3.2.2 *Effect of polypropylene on shrinkage cracking*

In Figure (7), it is clearly observed that increasing the polypropylene content to 0% (mix No. 29) causes a decrease in crack time to appear nearly 83.3% and a decrease in crack width of nearly 426.5%, increase in the polypropylene content to 0.7% (mix No. 16) . As a result, an increase in the polypropylene content greatly decreased the crack width which is the right way to use polypropylene as an additive in other research. While the crack with plain control concrete was above the recommended threshold, the addition of polypropylene reduced the width within the acceptable threshold compared to the mixture [13]. An Increase in shrinkage cracks combined with Tensions became even more pronounced. Although the increment rate was much more pronounced after the first 14 days were completed due to faster evaporation and absorption of mixing water in hydration reactions during this time. Forms of weight loss have proven this. Before 14 days of age, the weights of specimens declined sharply level-off after 28 days [14].

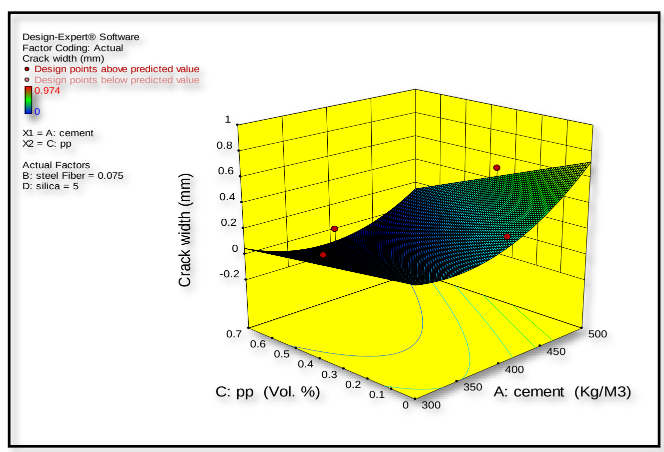

Figure 7. Effect of cement and P.P fiber volume on the Crack Width

3.3. CO2 Emissions and Cost for concrete mixtures

To get the purpose of the study regarding Eco-friendly mixtures, the costs of the materials used are estimated according to the cost prevailing in the local markets as shown in Table (11). As for the emissions, they come from production, transport, and work. This study depended on emissions from the process of production [15, 16]. The overall emission and cost values were obtained for 30 mixtures as shown in Table (12).

Table 11. The amount of emission and the cost of the mix

Item	kg CO2- e/kg	Cost/US$/kg
Cement	0.82	0.083
Coarse agg.	0.04	0.010
Fine agg.	0.0139	0.013
Silica fume	0.014	1.25
water	0.000019	0.021
Steel. fiber	1.85	5.00
P.P fiber	0.0095	8.33

Table 12. Summary of value of CO_2 emissions and Total Cost

Run mitures	*Cement kg/m³*	Steel fiber %	P.P fiber %	Silica fume %	kg CO2-e/m3	Total Cost (US$/m3)
1	400	0.075	0.35	5	391.712	137.138
2	400	0.075	0.35	5	391.712	137.138
3	400	0	0.35	5	381.467	108.101
4	500	0	0	10	456.055	126.029
5	300	0	0	0	306.902	50.243
6	400	0.075	0.7	5	391.446	163.275
7	500	0.15	0.7	0	478.646	174.641
8	400	0.075	0.35	5	391.712	137.138
9	500	0.075	0.35	5	467.325	150.323
10	500	0.15	0	0	479.123	122.343
11	400	0.075	0.35	5	391.712	137.138
12	400	0.075	0.35	5	391.712	137.138
13	300	0	0	10	305.295	87.274
14	500	0	0.7	10	455.538	178.316
15	400	0.15	0.35	5	401.943	166.162
16	500	0	0.7	0	458.156	116.565
17	300	0	0.7	10	304.778	139.562
18	300	0.15	0.7	10	325.268	197.637
19	300	0.15	0.7	0	326.822	160.582
20	500	0.15	0.7	10	476.014	236.378
21	300	0	0.7	0	306.385	102.530
22	300	0.15	0	10	325.786	145.349
23	400	0.075	0	5	391.964	110.988
24	300	0.075	0.35	5	316.085	123.940
25	500	0.15	0	10	476.434	184.090
26	300	0.15	0	0	327.339	108.295
27	400	0.075	0.35	5	391.712	137.138
28	400	0.075	0.35	0	392.774	112.442
29	500	0	0	0	458.673	64.278
30	400	0.075	0.35	10	390.676	161.831

4. Optimization of Preparation Parameters

To assess the optimal value of cement, silica fume, steel fiber, PP fiber, and crack width, an optimization procedure was applied. The optimal target for each mix design parameter was chosen within the appropriate value ranges based on the program optimization stage. For compressive and flexural strength, this was set to surpass (30 MPa) [5] and (4.1 MPa) [Hınıslıoğlu and Bayrak, 2004], respectively, which is the minimum criterion for design concrete pavement .The design of Eco-friendly mixtures was set to minimize CO2 and costs. The finalized crack widths 0.1mm are listed according to the adopted procedure [9]. It is known that small crack widths can self-repair concrete materials without external influence [17, 18] according to the healing. The results of the optimum value of variables and their response are shown in Table (13) and Figure (8).

Table 13. The optimum variables with their responses

Responses	Unit	Optimal results	Desirability
Cement	Kg/m3	385.944	0.882
Silica fume	%	0.00019	
Steel Fiber	Vol.%	0.0563	
PP fiber	Vol.%	0.2926	
Compressive Strength	Mpa	31.08	
Flexural Strength	Mpa	4.076	
CO2 emission	Kg CO2-e/m3	379.596	
Total Cost	US$	99.96	
Crack width	mm	0.1	

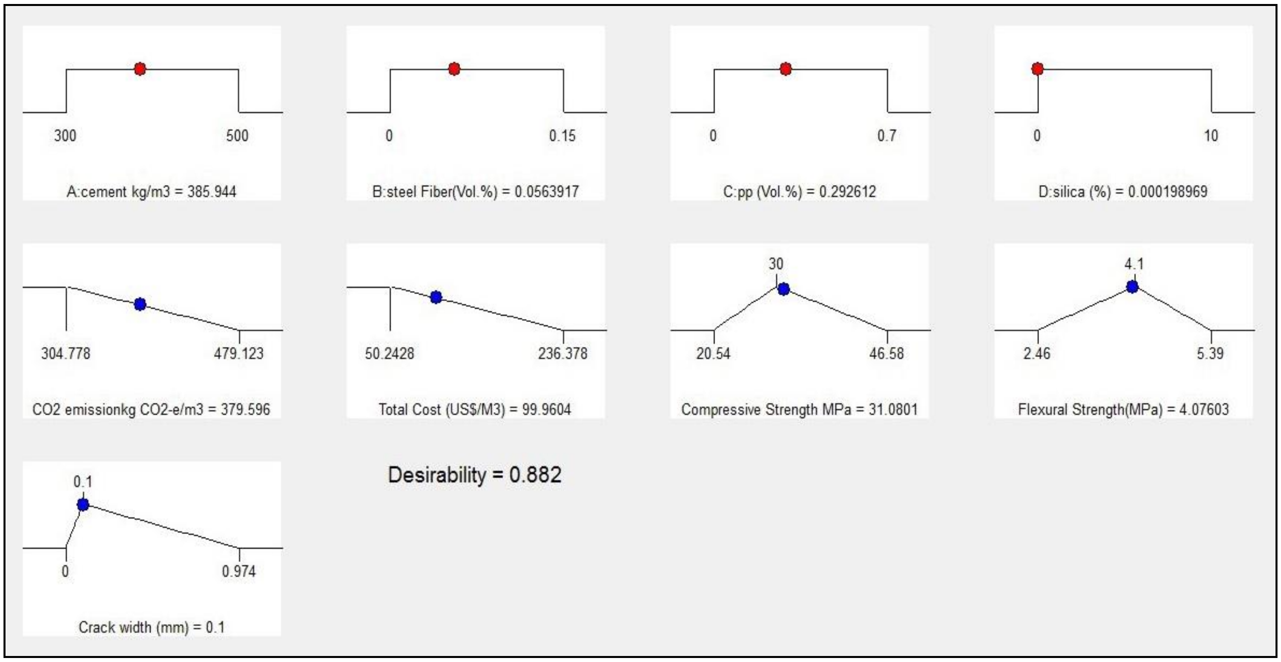

Figure 8. The optimum variables with their responses (DOE outcomes)

5. Conclusions

In the current research, the principal goal of this work is to develop optimal Eco-friendly concrete mixtures by using Response Surface Methodology (RSM), including different quantities of polypropylene fiber used in concrete pavement, identify the shrinkage factor (shrinkage cracking) in the concrete pavement. Efforts were made to design environmentally friendly concrete mixtures taking into account cost reduction and CO_2 emissions through the use of low cement were compressive and flexural strength requirements matched in Iraq. It drew the following conclusions:

1. Crack width in a less quantity of cement goes on the decrease in comparison with mixtures that have a high quantity of cement. Increase the cement content causes increases in the amount of shrinkage and increase the crack width to 96.9% in rings. However, the differences between shrinkage values cause cracks with a width of more than less content of cement.
2. An increase in the polypropylene content, cause the crack width to greatly decrease by nearly 425.5% in Rings samples.
3. The application of polypropylene decreased the width beyond the acceptable limit as compared with the mixture having the same volume of cement.
4. For the purpose of achieving the best design of concrete mixes used in the concrete pavement in this study which has minimum cracks width, minimum CO_2 emissions, minimum cost, compressive strength [> 30 MPa], and flexural strength [> 4.1 MPa], according to requirements and Iraqi specifications are cement [385.94] kg/m^3, silica fume [0.000198 Vol.%], steel fiber [0.0564 Vol.%], PP fibers [0.2926 Vol.%], Carbon dioxide emissions [379.59] kg CO_2-e / m^3, total cost 99.96 USD / m^3, and crack width [0.1]mm.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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