USING ECO-FRIENDLY CONCRETE MIXTURE FOR MINIMUM CRACKS RISK IN CONCRETE PAVEMENT AT EARLY-AGE

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Abstract: Early-age cracking occurs when tensile stresses exceed tensile strength in the concrete pavement. The task of optimizing a pavement for early-age cracking resistance is more complex, requires a more careful, and complete analysis. The main purpose of the present study is to design optimum Eco-friendly concrete pavement mixtures with low stress to strength ratio. The stress to strength ratio was predicted by using HIPERPAV software. The experiments were designed using a thirty mixtures with four factors, namely, the cement content 300,350 and 400 kg/m³, water/cementitious ratio of 0.3, 0.40 and 0.5, three different amount of fine/ aggregate ratios 0.3,0.4 and 0.5, And 0, 5, and 10% Silica fume by weight of cement. The results stated that, W/C ratio and silica fume ratios are the higher factors affecting the stress to strength ratio. Finally, the optimal components to design concrete mixtures used in pavement that having low strength to stress ratio with (63%), compressive strength of (34.4 Mpa) and flexural strength of (4.1 Mpa) where found to be: cement 360.5 kg/m³, silica fume 5.1%, F/A ratio of 0.3, and W/C ratio of 0.5.

Keywords: concrete pavement; crack risk, Eco- friendly concrete, stress to strength ratio.

1. Introduction

Cracking is one of the key issues in concrete pavement design and construction. Cracks reduce the serviceable life of the pavement. Cracks cause the agency to have higher repair and reconstruction costs because they increase

the pavement's roughness and because they are costly and difficult to maintain. Concrete pavements are supposed to have very low maintenance costs for several years of operation, so prevention of early cracks is particularly important. If early-age cracks occur, the pavement may need increased maintenance and eventually rehabilitation from the start of its life cycle. Portland cement (PC), the initial binder, is among others the most power-intensive ingredient in plain concrete. Production cement shares 8 percent to CO₂ emissions [1]. However, binder-rich (raised PC content) mix proportions are required particularly for high-performance concrete (HPC), which raise the risks of dimensional instability and environmental unfriendliness [2].

As above-mentioned, in spite of attention about the production of high quantities of (PC), the inclination of several modern studies is to manufacture sustainable concrete mixes [3–5]. The idea of manufacturing increased Eco-friendly concrete can be achieved by decreasing the amount of CO₂ [6, 7]. Rich cement mixes resulting in a raise in concrete strength. It may,

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in turn, induce shrinkage. Concrete may produce stresses that exceed its tensile limit; cracks may therefore show [8]. HIPERPAV (High PERFORMANCE concrete PAVing) is a concrete pavement software product sponsored by the Federal Highway Administration (FHWA) [9]. HIPERPAV allows users to evaluate the complicated interactions that influence the concrete paving behavior at early ages. Sufficient selection and monitoring of these factors (mix proportions, curing condition, time of saw cutting, time of casting, etc.) will raise the chances of perfect performance during the intended design life of the pavement. Using HIPERPAV questions attach to material chosen, pavement design, and construction procedure can be estimated, as its integrated method takes most sides of concrete pavement construction and supplies a systems method to analyze the first 72 hours after construction.

2. Purpose of the study

The objective of this study is to optimize the concrete mixture ingredients that use in the rigid pavement for minimizing the risk of the crack induced shrinkage at early-age which simulated by HIPERPAV software.

3. Materials Used, Test, and Mixture Design

3.1. Material

3.1.1 Cement

The cement used during this work was Type I (Ordinary Portland Cement) of the Tasluga Factory. It was kept in airtight plastic containers to prevent exposure to different atmospheric conditions. The chemical analysis and the physical test results conformed to the Iraqi standard No. 5/1984[10].

3.1.2. Fine aggregate

The natural sand from Al-Ukhaider region is used in a concrete mix to achieve the Iraqi specification for the mid-range gradient. The distribution of particle sizes is shown in Fig.1.

Figure 1. Gradation for Fine Aggregate.

3.1.3. Coarse Aggregate

The crushed gravel from AL-Niba'ee is used in a concrete mix to achieve the Iraqi specification for the mid-range gradient. Coarse aggregate gradation is shown in Fig.2.

Figure 2. Gradation for coarse aggregate

3.1.4. Mixing Water

Water is a main constituent of concrete mixtures; It reacts chemically (hydration) with Portland cement to produce the desired concrete properties. During the Casing and Curing process drinking water was used.

3.1.5. Silica Fume

Micro Silica material has been used in mixes of concrete with different weight ratios for cement. The Micro-Silica fume (SF) is a very active pozzolanic material. The, SO_3 , SiO_2 and L.O.I were 0.23, 94.1 and 3.6, respectively

3.2 Sample Preparing and Test

In accordance with the principal purpose of this investigation, three Cubic specimens with a dimension of 100 mm were prepared to test compressive strength, Also, three Prism specimens measuring 100 x100x500 mm were cast and then tested for flexural parameters under four-point bending/loading: flexural strength based on Modulus of Rupture (MOR) [11]. After 1 day, both cubic and prismatic specimens were moved to be further cured in water until 7, 28 days were finished.

3.3 Mixtures design

In the present study four considerations are adopted, namely; cement content, silica fume (SF), fine/aggregate (F/A) ratio and water/cementations (w/c) ratio. Factors and their levels are given in Table (1). The thirty mixes (Table 2) were designed according to the Central Composite Design (CCD) which is the most important of every single quadratic design and normally utilized in (RSM).

Table 1 .The four factors and the levels utilized

Factors	low level	mean level	high level
Cement (kg/m3)	300	350	400
water/cementations	0.3	0.4	0.5
Silica fume	0	0.05	0.1
fine/course aggregate	0.3	0.4	0.5

Table 2. Array of experimental design by RSM

Run (Mixture No.)	Cement	W/c	F/c	SF
1	350	0.4	0.4	0
2	350	0.4	0.4	0.1
3	350	0.4	0.3	0.05
4	400	0.5	0.5	0.1

Run (Mixture No.)	Cement	W/c	F/c	SF
5	300	0.3	0.3	0.1
6	350	0.4	0.4	0.05
7	350	0.4	0.4	0.05
8	400	0.5	0.3	0.1
9	350	0.5	0.4	0.05
10	300	0.3	0.5	0.1
11	350	0.3	0.4	0.05
12	400	0.3	0.3	0.1
13	350	0.4	0.4	0.05
14	350	0.4	0.4	0.05
15	400	0.3	0.5	0
16	400	0.4	0.4	0.05
17	300	0.5	0.5	0
18	400	0.3	0.3	0
19	400	0.5	0.3	0
20	300	0.3	0.5	0
21	400	0.3	0.5	0.1
22	300	0.5	0.3	0.1
23	300	0.5	0.3	0
24	400	0.5	0.5	0
25	300	0.4	0.4	0.05
26	350	0.4	0.4	0.05
27	350	0.4	0.4	0.05
28	350	0.4	0.5	0.05
29	300	0.3	0.3	0
30	300	0.5	0.5	0.1

4. Results

As above-mentioned, four factors: cement amount, silica fume (SF), W/C, and F/A ratios were selected to investigate their effects on the cracks risk in terms stress/strength ratio that induced at early-age of the concrete pavement. Compressive strength and flexural strength were tested in the laboratory. In addition, the cost and the CO₂ emissions for each mixture were estimated, based on the emission of each component at production. Finally, the stress-strength ratios were calculated from the HIPERPAV software. The summary results of the above variables are listed in Table 3. In the current study, the design of experiments (DoE) is used. The DoE seeks the choosing of most suitable points (tests) in which the response (output) must be well tested. Thus, the use of experiment design has a large rule in choosing the connected response surface test [12].

Table 3. Summary of results of mechanical properties

Mix No.	Emission (Kg CO ₂ - e/m ³)	Total Cost (US\$/ m ³)	Compressive strength (Mpa) at 28 days	Flexural Strength (Mpa) at 28 days	Stress to Strength (%)
1	351.80	54.0871	29.7	3.39	95.40
2	352.90	97.3149	36.8	4.20	58.20
3	353.75	75.0253	33.6	3.83	61.60
4	405.10	107.218	40.1	4.53	95.60
5	305.70	87.1757	30.8	3.54	97.90
6	356.85	75.6992	35.1	4.01	86.50
7	357.85	75.6992	34.3	3.91	61.00
8	408.90	106.053	45.7	5.16	97.90
9	359.95	75.3821	30.1	3.43	74.10
10	310.90	88.6267	29.6	3.40	97.00
11	361.75	76.0297	32.9	3.75	96.80
12	412.70	106.743	44.6	5.04	99.60
13	363.85	75.6992	33.5	3.82	61.30
14	364.85	75.6992	31.8	3.62	62.00
15	415.80	58.6519	37.0	4.18	100.3
16	416.85	82.3125	41.5	4.69	98.90
17	318.00	50.9902	24.7	2.84	94.40
18	418.60	57.2678	38.0	4.29	101.8
19	419.80	56.6530	37.5	4.24	72.00
20	320.80	51.5688	23.7	2.73	100.8
21	421.90	108.063	41.3	4.67	99.40
22	322.90	86.6634	31.4	3.61	74.70
23	323.80	49.6159	26.3	3.02	96.70
24	425.00	57.8838	36.6	4.14	70.70
25	325.85	69.0895	27.9	3.21	98.70
26	376.85	75.6992	32.6	3.72	61.60
27	377.85	75.6992	33.5	3.82	61.30
28	378.95	76.3766	31.5	3.59	61.70
29	329.60	50.0776	25.5	2.93	101.2
30	331.10	87.9866	29.1	3.35	74.20

4.1 Screening and variables analyses

Screening analysis is an important tool used to study the significance of a set of variables on predicted stress to strength ratio (i.e. crack risk) to choose the most essential contributing variables. The experiment program design was used in this paper, which presents its findings using a Pareto chart as shown in Fig.3. This figure shows the most important parameters which affect crack risk by an order. The W/C ratio has the most significant impact followed by silica fume, fine-to-course aggregate ratio (F/A), cement.

4.2 Effect of W/C ratio and silica fume on stress to strength ratio (crack risk)

After doing the screening, it is found those W/C ratio and silica fume ratios are the higher factors affecting the stress to strength ratio. Fig.4 shows the relation between the two factors and the stress to strength ratio.

Figure 3. The outcomes of the screening analysis for the stress to strength ratio

Figure 4. Effect of W/C ratio and silica fume on the stress to strength ratio

Figure 5. The optimum variables with their responses (DOE outcomes)

5. Optimization of Preparation Parameters

An optimization process to determine the optimum value was implemented of cement, silica fume, W/C ratio and F/C ratio. Based on to the Design of experiment (DOE) 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 minimum requirement for design concrete pavement (SORB, 2003) [18]. Minimizing CO₂ and cost were set to design Eco-friendly mixtures. Finally, the stresses to strength ratio were adopted to be minimum.

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 Fig. 5.

6. Conclusions

In the present study, efforts were made to design Eco-friendly concrete mixtures taking into account lowering stress to strength ratio of the concrete pavement at early-age. The following conclusions were drawn:

1. It is found that W/C ratio and silica fume ratios are the higher factors affecting the stress to strength ratio (crack risk)
2. Optimal components to design concrete mixtures used in pavement that having minimum stress to strength ratio with (63%), compressive strength of 34.4 Mpa) and flexural strength of (4.1 Mpa) are cement 360.5 kg/m³, silica fume 5.1%, F/C ratio of 0.3, and W/C ratio of 0.5.

Conflict of Interest

The authors declare no conflicts of interest

7. References

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